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SPECIAL NOTICE

The Recommendations of the Joint Committee on Metallurgical Education, for Qualifications for Entrance to University Schools of Metallurgy, are published, in full, on pages 157–158.

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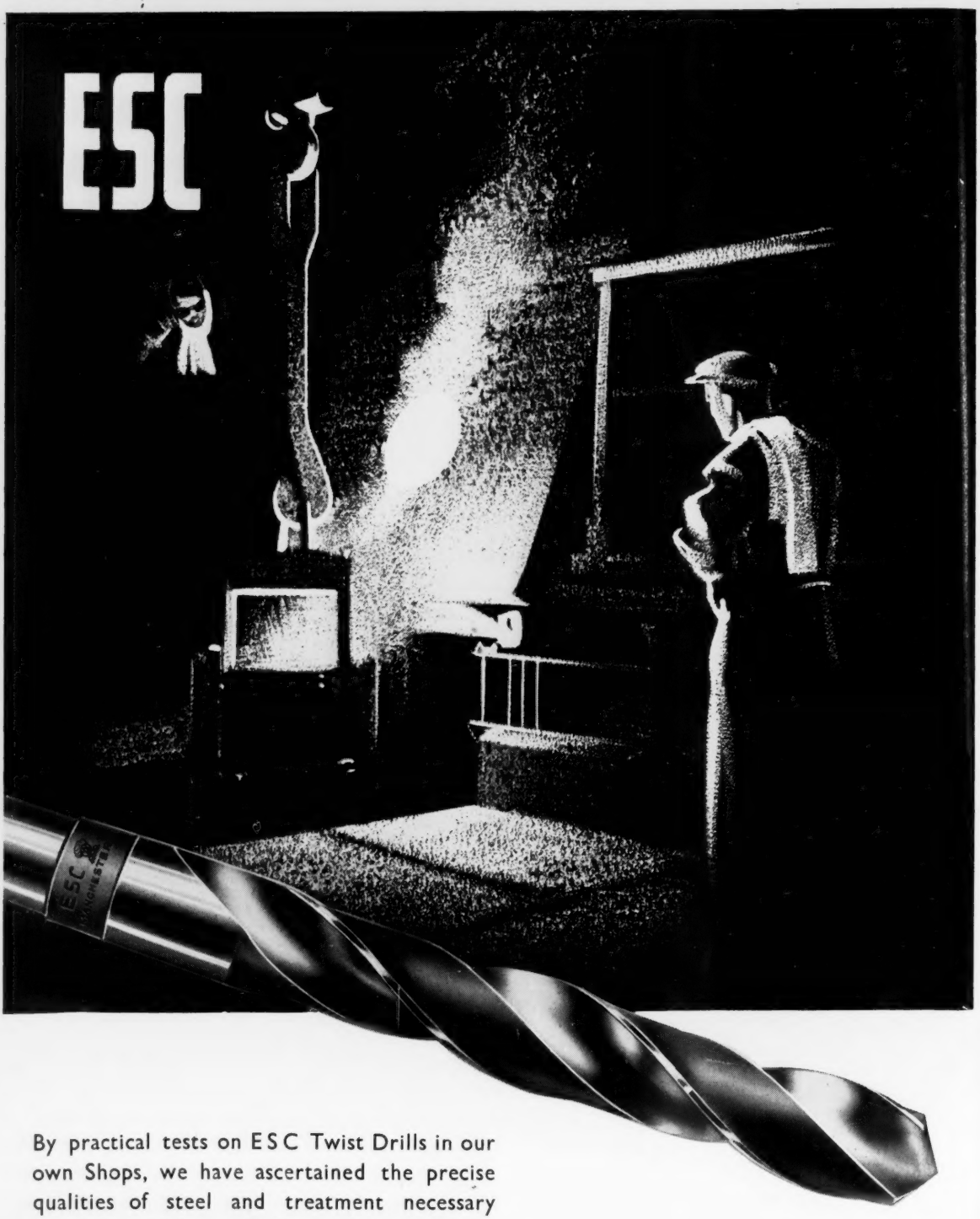

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FRANK HENRY SANITER, B.Eng.

FRANK HENRY SANITER succeeded the late Dr. T. Swinden as Director of Research to The United Steel Companies, Ltd., in 1945. Born at Rotherham in 1906, he is the son of the late Mr. E. H. Saniter who was elected a Member of the Institute in 1892, a Member of Council in 1921, and a Vice-President in 1927. Mr. F. H. Saniter was educated at Rotherham Grammar School, at Sedbergh School, and at the University of Sheffield, graduating with the degree of B.Eng. in mechanical engineering in 1926. In the same year he joined the firm of Steel, Peech and Tozer, as assistant to Mr. Gerald Steel, and there he was engaged in the development of their trade in alloy and special steels. This work was continued when, in 1930, he transferred to Samuel Fox and Co., Ltd., following the decision of The United Steel Companies, Ltd., to concentrate the manufacture of alloy and special steels at their Stocksbridge Works.

From 1940 to 1945 he was loaned to the Ministry of Supply. During this period he was technical advisor to the British Iron and Steel Corporation in New York, and later to the British Raw Materials Mission (iron and steel division) in Washington. Subsequently, he became deputy director of the iron and steel division. He also served on the staff of the Combined Raw Materials Board, and as a Member of the British-American-Canadian Committee which met in 1943 to study the conservation of steelmaking alloys. He was a member of the Combined Intelligence Objectives Sub-Committee (C.I.O.S.) team which made an initial survey of the wartime activities of the German iron and steel industry in June, 1945. Since his appointment as Director of Research he has been responsible for the administration and enlargement of the Companies' Research and Development Department.

Mr. Saniter is associated with a large number of technical societies and committees : He is a Member of Council of the British Iron and Steel Research Association, and a member of that Association's Divisional Panels on Metallurgy, Ironmaking, and Mechanical Working. He is also a member of the Iron and Steel Industry Committee and the International Standards Liaison Committee of the British Standards Institution ; a member of the Consultative Committee on Iron and Ferro-Alloys of the Imperial Institute ; a Member of Council of the Sheffield Society of Engineers and Metallurgists. He joined The Iron and Steel Institute in 1935 and was elected a Member of Council in 1947.

F. H. Samiter, B.Eng.
Member of Council

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

THIRD HATFIELD MEMORIAL LECTURE

The Decomposition of Austenite by Nucleation and Growth Processes

By Robert Franklin Mehl, Ph.D., D.Sc., D.Eng.

In considering a subject for this Hatfield Memorial Lecture, I have not been unmindful of what appeared to be the predilection of the Lecture Committee, that I should speak upon transformations in steel. This subject seemed appropriate to me, for the catholicity of Dr. Hatfield's activities in the metallurgical field led him to manifest a deep and discerning interest in such matters, as the pages of the transactions of this Institute abundantly show, and the subject is thus one that would have interested him. Perhaps in this way this lecture may be taken as a tribute to him, to his long labours in the advancement of metallurgy, and to the beneficent influence he exerted. This subject is indeed one which has been pursued at some length in the laboratory with which I am associated, and I shall enjoy putting our views before you.

It is now quite well recognized that the properties of annealed and normalized steels are determined by the structures formed at high temperatures, and it has been learned, increasingly in recent years, that these structures are determined by the rates of formation of the ultimate structures in the temperature ranges in which reaction occurs, and by the interdependent morphology. In the very important group of steels that are quenched for hardening, however, the success of this operation largely rests upon the ability to choose steels for which commercial quenching operations are rapid enough to avoid appreciable formation of the high-temperature reaction products. Thus, obversely, the proper study of hardenability is in large part also the study of the rates of these high-temperature reactions.

These reactions consist of the formation of the pro-eutectoid constituents ferrite and carbide, the formation of pearlite, and at lower temperatures the formation of bainite. They proceed by nucleation and growth, certainly for the first-named constituents, and possibly also for bainite. It is to this subject, these nucleation and growth processes, that this lecture is addressed. The subject is not yet far advanced, but enough has been done to permit this appraisal and to anticipate those lines along which research might most profitably follow.

In considering the fundamental question of the kinetics of these reactions, detailed attention must be given to the morphology of the resultant constituents. In reactions within solids, kinetics and morphology are interdependent, for the detailed characteristics of kinetics determine the shape and spatial distribution of the products, and the latter in turn affect the overall rate of the reaction. Both rate and morphology are best studied by isothermal reaction, and this is the approach that will be used. The correlation of isothermal rates of reaction with the phenomena occurring on cooling is not a subject of extraordinary difficulty, and in some respects is well advanced.

The Lecture was presented on 5th May, 1948, in the Lecture Hall of the Royal Institution of Chartered Surveyors, 12, Great George Street, London, S.W.1.

Dr. Mehl is Director of the Metals Research Laboratory, and Professor of Metallurgical Engineering, at the Carnegie Institute of Technology, Pittsburg, Pa., U.S.A.

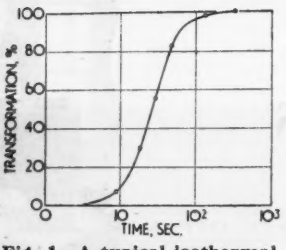


Fig. 1—A typical isothermal reaction curve

ISOTHERMAL REACTION—THE TYPES OF STEEL

At a temperature below the A_{e_1} temperature, austenite will decompose on cooling or may be decomposed isothermally. The isothermal rate, measured usually microscopically or dilatometrically, is represented by an isothermal reaction curve, in which the fraction transformed is plotted against time, Fig. 1. These curves, taken at a series of temperatures, are usually assembled into an isothermal transformation diagram, by the device of plotting the beginning of the reaction at, say, 1% reaction and the end of the reaction at, say, 99% reaction.

Figure 2 shows such an isothermal transformation diagram for a eutectoid carbon steel. Above the knee of the curve at about 570° C. pearlite forms, and below the knee, bainite. At a low temperature, martensite forms, represented on this diagram by a horizontal line to indicate the beginning of the reaction. The martensite reaction occurs substantially only on cooling, not isothermally ; it does not form by nucleation and growth, but by shear unaccompanied by diffusion, and is not considered further in this lecture. Figure 3 is a similar curve for a hypo-eutectoid carbon steel, showing the formation of pro-eutectoid ferrite preceding the formation of pearlite, the amount of the pro-eutectoid constituent decreasing as the temperature decreases and approaching zero at the knee. Hypereutectoid steels have a similar type of isothermal diagram, with pro-eutectoid cementite replacing pro-eutectoid ferrite.

The isothermal decomposition of alloy steels may be represented in a similar fashion. In Fig. 4, which shows an isothermal diagram for a 4% nickel steel,

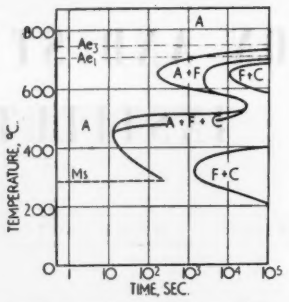


Fig. 5—Isothermal transformation diagram for a steel with 0·42% carbon, 0·76% manganese, 1·79% nickel, 0·80% chromium, 0·033% molybdenum, grain-size 7–8 (U.S. Steel Corporation Research Laboratories)

it is observed that nickel merely displaces the curve to the right, in terms of cooling, providing deeper hardening, while the shape of the curve is not changed. Figure 5 shows an isothermal diagram for a chromium–nickel–molybdenum steel ; here the pearlite region is seen to be displaced to the right, but also the curve now is more complex, with a pro-eutectoid constituent resembling ferrite forming down to quite low temperatures. This complexity in the form of isothermal diagrams for alloy steels reflects the complexity in the mechanism of the reactions which such steels exhibit.

These are now elementary matters, but they are introduced here because the reaction characteristics of each of these main types of steel will be considered in some detail.

THE CHARACTERISTICS OF PROCESSES OF NUCLEATION AND GROWTH

The decomposition of austenite at sub-equilibrium temperatures, either on cooling or isothermally, is a typical heterogeneous reaction, proceeding by the formation of nuclei and their subsequent growth. All heterogeneous reactions, for all states of aggregation, proceed in this way, except those solid–solid reactions which, like martensite, proceed by shear. In the most general case, as shown in Fig. 6, the nuclei form at random and each grows. Nuclei continue to form with time, and each grows to a nodule, striving to

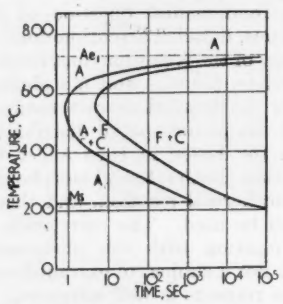


Fig. 2—Isothermal transformation diagram for a eutectoid steel with 0·79% carbon, 0·76% manganese, grain-size 6 (U.S. Steel Corporation Research Laboratories)

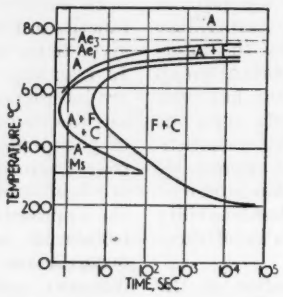


Fig. 3—Isothermal transformation diagram for a hypo-eutectoid steel with 0·50% carbon, 0·91% manganese, grain-size 7–8 (U.S. Steel Corporation Research Laboratories)

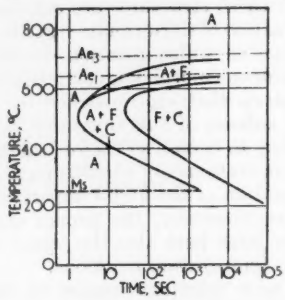


Fig. 4—Isothermal transformation diagram for a steel with 0·55% carbon, 0·33% manganese, 3·88% nickel, grain-size 8–10 (U.S. Steel Corporation Research Laboratories)

form a spherulite, with growth ultimately restricted by impingement with other growing nodules.

This ideal case of nucleation and growth, when the rate of nucleation and the rate of growth are both constant with time, may be expressed mathematically as :

$$f(t) = 1 - e^{-\frac{\pi}{3}NG^3t^4}$$

where the fraction transformed, $f(t)$, is given in terms of the rate of nucleation N, the rate of growth G, and the time t. Such a reaction equation produces a reaction curve of the type shown in Fig. 7, identical in character with the experimental isothermal reaction curve for pearlite shown earlier (Fig. 1).

This treatment applies well, indeed nearly perfectly, to pearlite formed at high temperatures. In other cases, modifications must be made in the reaction-rate equation, but these modifications relate only to alterations in the analytical form, including allowance for the formation of reaction products which have geometrical forms other than that of spherulites, and do not affect the basic principle, that the rate of nucleation and the rate of growth determine the isothermal rate of reaction. The factors that determine the rate of nucleation and the rate of growth, and the contribution that theory can make with respect to each of these rates, must therefore be studied.

THE FORMATION OF PEARLITE IN EUTECTOID CARBON STEELS

The formation of pearlite in eutectoid carbon steels is a good point of departure ; as compared to hypo-eutectoid or hypereutectoid steels, pearlite is relatively simple, and it illustrates many of the basic principles for all compositions.

Consider first the formation of pearlite near A_{e1}. The isothermal reaction curve is that shown in Fig. 1. Microscopically it is observed that nuclei form at the austenite grain boundary and grow to large nodules. Each of these nodules is composed of the pearlite colonies of Belaiew, Fig. 8, areas formed as a unit, usually with but one direction of lamellæ, in which the ferrite and the cementite have each a single orientation. The original nucleus, a cementite platelet, appears and in time thickens, then a parallel lamella of ferrite deposits and in turn thickens, then cementite again, and so on, all lamellæ meanwhile growing

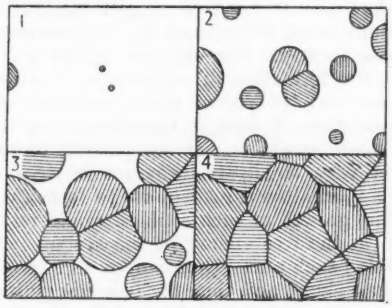


Fig. 6—Diagram depicting the progress of transformation in a nucleation and growth process. Four stages at equal intervals of time

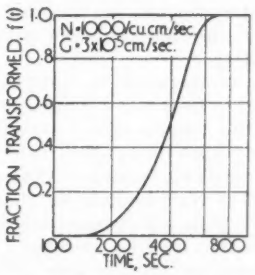


Fig. 7—Calculated reaction curve for general nucleation

edgewise also, creating the pearlite colony. The formation of a pearlite colony thus seems to proceed by edgewise growth, that is, in the direction of the lamellæ, and also by sidewise nucleation and growth. This first colony in turn nucleates other colonies, so that a nodule forms by the successive formation of colonies, Fig. 20.

The rate at which these nuclei form, and the rate at which they grow have surrendered to measurement. It has been shown that the number of nuclei formed in a given period of time for a steel in different grain-sizes varies with the extent of the grain-boundary surface, *i.e.*, that the basic value of the rate of nucleation is essentially the rate per unit grain-boundary area ; except for substantial austenite heterogeneity, the rate of nucleation within the grain is of no consequence—indeed this may be employed as a quantitative test of austenite heterogeneity ; inclusions, though active occasionally as inoculants, in fact play an exceedingly minor part. It is, of course, in this predominating exclusiveness of grain-boundary nucleation that the effect of grain-size on reaction rate and the correlative hardenability lies. On this basis the effect of grain-size on hardenability has in fact been appraised by Grossmann.

The rate of nucleation, surprisingly, is not a constant with time, as Fig. 21 shows. This has been observed in all cases in the decomposition of austenite, even for heterogeneous austenite, and also in the somewhat similar case of nucleation and growth during recrystallization ; it may, in fact, be a general phenomenon in nucleation processes (investigators of the more conventional types of nucleation processes appear not to have investigated the point).

The rate of growth of a pearlite nodule as measured is the rate of growth of successive colonies. Measurements show this to be very close to the true rate of edgewise growth, Fig. 22. Now pearlite represents the complete decomposition product of austenite, that is, the composition of austenite away from the pearlite–austenite interface does not change ; decomposition is initiated and completed at the moving pearlite interface. Accordingly, it is not surprising that the rate of growth of pearlite is constant with time. Moreover, pearlite grows across austenite grain boundaries with no perceptible retardation, and is in no way affected by austenite heterogeneity. In a word, it is a fundamental characteristic of the rate of growth that it is not structure-sensitive. The rate of nucleation, however, far higher in the disorder of

the grain boundary than within the grain, and strongly accelerated by austenite heterogeneity, is sharply structure-sensitive.

Near the A_{e1} temperature the rate of nucleation is small compared to the rate of growth, with the result that the pearlite nodule grows very large, Fig. 9, absorbing many austenite grains, before it impinges upon another growing nodule. Even though the nuclei originate at grain boundaries, their distribution is on such a fine scale with respect to the final nodule size that nucleation may be considered as effectively random. Taking an average rate of nucleation to represent the rate changing with time, the reaction at high temperatures thus very closely approximates the idealized case first pictured, and the isothermal-reaction-rate curve may be closely calculated from the rate of nucleation per unit austenite grain-boundary surface and the rate of growth.

At temperatures near the knee of the isothermal diagram, the morphology of pearlite changes. Microscopic evidence, Fig. 10, gives direct proof that nucleation is predominantly at the grain boundary ; here again, and in fact throughout the temperature range in which pearlite forms, the rate of nucleation must be expressed as the number of nuclei formed in unit time per unit austenite grain-boundary surface. Near the knee of the isothermal diagram the rate of nucleation per unit austenite grain-boundary surface is very high, with many pearlite nodules forming per grain. The result of this is that the mode of growth is quite different : each nodule grows but a small way before it impinges upon another growing nodule, whence these nodules grow toward the centre of the grain roughly in the shape of sectors. It is clear that the morphology of pearlite nodules is dependent upon the ratio of the rate of nucleation and the rate of growth ; this ratio is high at temperatures near the knee, and low at temperatures near A_{e1}.

The morphological characteristics of the reaction at temperatures near the knee distinguish the reaction from the ideal assumption of random nucleation and random impingement originally assumed in deriving the reaction equation ; but the reaction equation can be modified to take into account this different type of growth geometry, and this has been done. Whereas in truly random nucleation and growth the form of the isothermal reaction curve is always of the same shape, in the case of reaction near the knee a series of shapes may eventuate, all predictable, depending upon the relative values of the grain-size, the rate of nucleation, and the rate of growth. No mystery on this aspect of the formation of pearlite remains.

The Rate of Nucleation—Experimental Evidence and Theory

Rates of nucleation have been measured in a number of pure and commercial iron–carbon alloys of eutectoid composition, over the full temperature range. One of the curves obtained is shown in Fig. 23 and represents an *average* rate of nucleation, suppressing the variation of this quantity with time. All curves thus far measured are similar to this. It will be observed that the rate is presumably zero at the equilibrium temperature and reaches a high value near the knee of the isothermal diagram.

The active nucleus in this reaction is almost certainly cementite. The evidence for this is of several kinds. Determinations of the orientation of ferrite in pearlite with respect to the parent austenite show it to be quite different from the orientation when ferrite is known to nucleate directly from austenite, as in the γ–α transformation in pure iron or as in the formation of pro-eutectoid ferrite from austenite ; the only conceivable explanation is that cementite acts as the nucleus and that the ferrite, forming subsequently, derives its orientation from the orientation of the cementite. Moreover, it is observed that residual cementite in austenite is a powerful inoculant for pearlite, whereas ferrite is not. It is in fact observed that the cementite in pearlite in hypereutectoid steels is continuous with the grain-boundary pro-eutectoid cementite, whereas the ferrite in pearlite is not continuous with pro-eutectoid ferrite in hypoeutectoid steels.

The variation of the rate of nucleation with temperature is in accord with formal nucleation theory. This theory, developed originally by Gibbs to apply to heterogeneous reactions generally, provides an expression for the rate of nucleation and a formal treatment of its variation with temperature. Reactions proceed only when the free energy of the system as a whole decreases ; it is not necessary that the free energy go to the lowest possible, that is, the equilibrium value. This is a highly important qualification for metallurgists, for it provides that intermediate stages may form, characterized by values of free-energy change less than the maximum ; chemists will remember Ostwald's law of stages ; and in this circumstance lies the great opportunity, which metal systems fully exercise, of forming a multitude of intermediate stages. The cementite in pearlite itself is unstable, and forms only because its rate of formation is greater than that of the stable phase graphite ; martensite is not a stable phase, but a transition structure having many features in common with the transition lattices in age-hardening systems responsible for the hardening that occurs ; and any disperse system, such as pearlite, is unstable with respect to a system of the same phases in which each constituent is a single crystal—in pearlite appreciable amounts of energy reside in the ferrite–cementite interface ; when pearlite is spheroidized it is this energy which is the driving force.

When a new phase forms, the free energy of the system decreases, that is, free energy is made available, the amount being determined by the volume of the new phase formed. The creation of the new phase involves the formation of an interface between the new phase and the parent phase, and this requires the expenditure of energy, furnished from the free energy made available. If the particle of the new phase is very small, the amount of free energy available is small and inadequate to form the interface. The growth of such a phase would require an increase in the free energy of the system, which is impossible ; such nuclei thus cannot form and grow. Since the volume and thus the free energy increases with the cube of the radius while the interface increases with the square of the radius, there will be a given radius—a larger radius—at which the free energy made available by this larger volume exactly

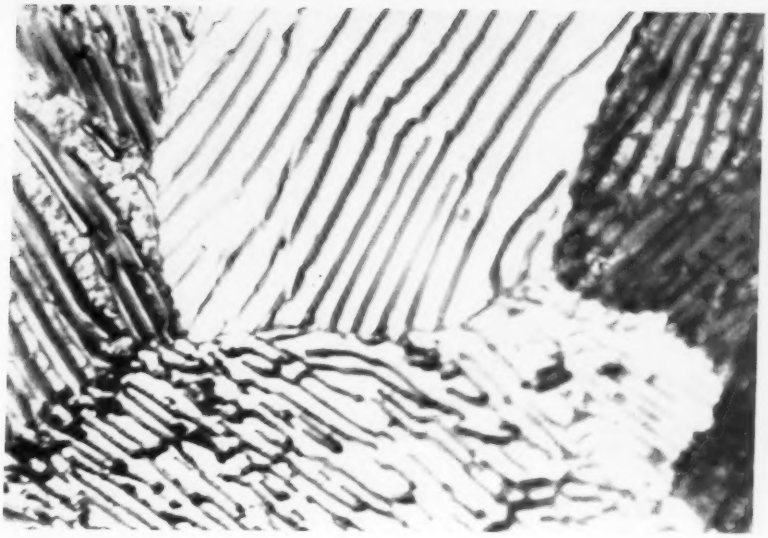


Fig. 8.—Pearlite colonies in a eutectoid steel transformed at 715° C. Electrolytically polished and etched with Vilella's reagent × 2500

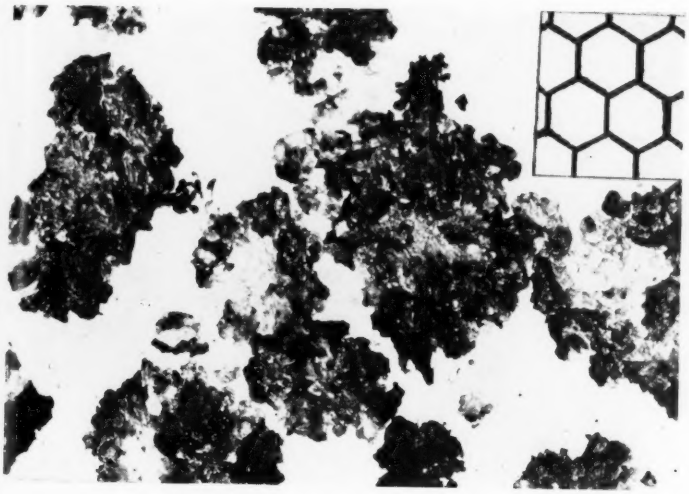


Fig. 9—Pearlite nodules formed in eutectoid steels after 9 min. at 680° C. Austenite grain-size shown by inset sketch × 100

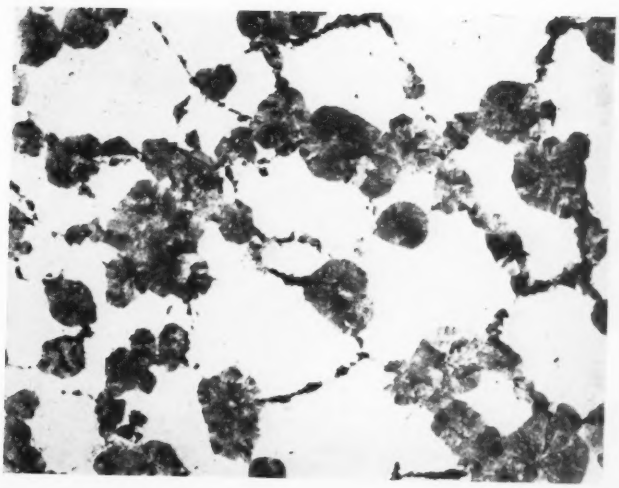


Fig. 10—Grain-boundary transformation in eutectoid steel upon quenching from 800° C. × 100

[Mehl

[To face p. 116

Fig. 11—Ferrite crystals formed at grain boundaries after reaction at 725° C. for 30 sec. in a hypo-eutectoid steel. Small grains × 500

Fig. 12—Ferrite plates growing from grain-boundary crystals in hypo-eutectoid steel after reaction at 675° C. for 10 sec. Small grains × 1000

Fig. 13—Grain-boundary reaction in a hypo-eutectoid steel reacted at 750° C. for 2½ hr. × 100

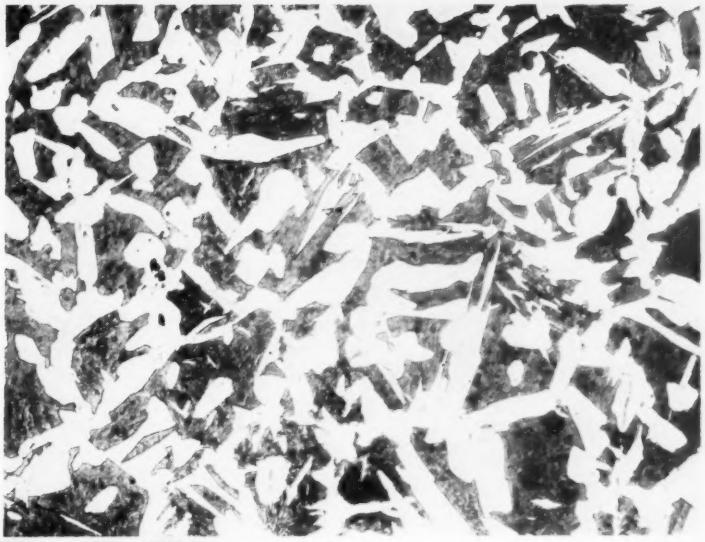


Fig. 14—Microstructure in a hypo-eutectoid steel after reaction of 24 hr. at 700° C. × 100

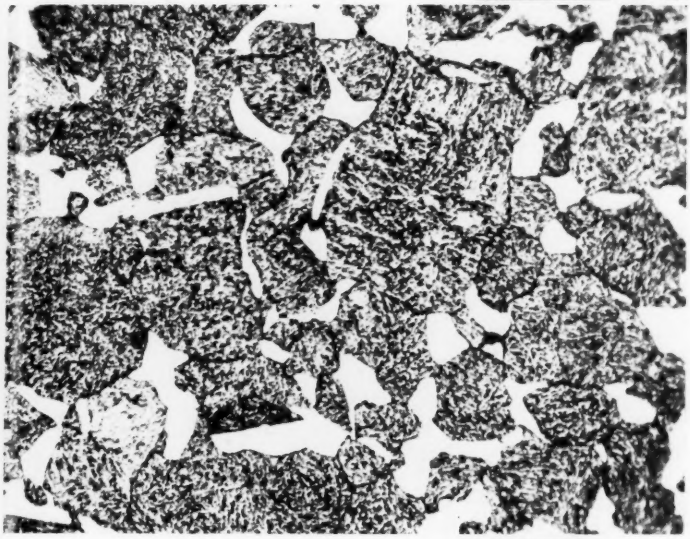


Fig. 15—Microstructure depicting preferential growth of ferrite along the austenite grain boundaries in a hypo-eutectoid steel. Etched with nital and then with Vilella's reagent × 500

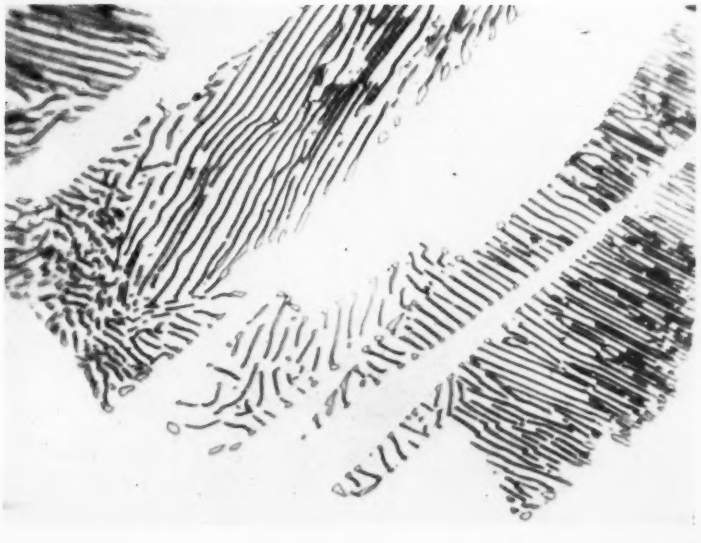


Fig. 16—Microstructure illustrating the thickening of cementite plates at a pearlite–ferrite interface. Etched with picral × 2000

[*Mehl*

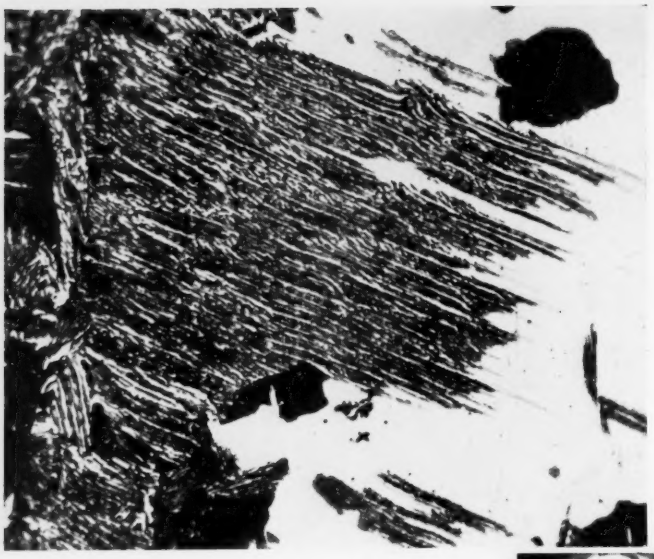


Fig. 17—" Upper bainite " for eutectoid steel partially reacted at 540° C. (Vilella)
× 1500

Fig. 18—" Lower bainite " in eutectoid steel formed upon reaction at temperatures near the martensite range (Vilella)
× 2500

Fig. 19—" X - constituent " formed in steel with 0·16% carbon, 3·36% nickel, 0·52% manganese, 0·20% molybdenum, reacted in upper region of bainite range (Vilella)
× 2000

equals the energy requirement for the formation of the interface. Such a nucleus is stable, and it can grow, as can any larger nucleus. The mechanism by which these nuclei come into being, associated with normal fluctuations in concentration and the corresponding diffusion rates and interaction energies, is not well understood.

The stable nucleus size should, according to this scheme, decrease with temperature, and the rate of nucleation calculated from it should increase with decrease in temperature. These considerations, relatively easy to apply to simple heterogeneous reactions, such as the condensation of vapour, encounter major and still unresolved difficulties in solid–solid reactions. This is primarily though not exclusively because the values of the interface energies between solids are entirely unknown and thus far unmeasurable. Since one solid phase forming from another is always oriented, that is, the crystal faces in juxtaposition are selected faces, the energies of specific interface couples would have to be treated, and since lattice coherency between the two phases usually obtains, strain energies must modify the interface energy. In a word, thus far only a thoroughly qualitative theory with respect to the rate of nucleation has been developed.

When considering alloy steels the difficulties in this respect will increase. The study of the rate of nucleation is now restricted to a purely inductive approach ; this is regrettable, for the rate of nucleation is much the more important variable in determining the rate of decomposition of austenite, and the host of engineering and practical matters depending upon that.

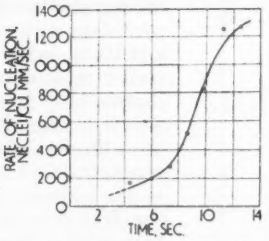


Fig. 21—Rate of nucleation of pearlite as a function of time. Eutectoid steel reacted at 680° C.

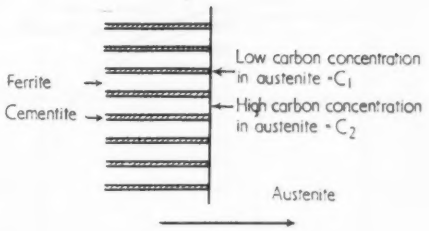


Fig. 22—Simplified model showing the edgewise growth of pearlite

The Rate of Growth

The lesser variable, the rate of growth, may be much more readily treated in a quantitative way. Once the growth of a colony is established, by the mechanism postulated earlier, further growth is edgewise, a phenomenon clearly apparent in the radial growth near the knee of the isothermal diagram, and quite obvious where pearlite nodules are formed partially at one temperature and then grown farther at another.

The rate of growth is easy to measure, and measurements are available on a number of commercial and pure iron–carbon alloys. The rate of growth increases with decreasing temperature of reaction, though not so rapidly as the rate of nucleation. One of the curves obtained is shown in Fig. 23 ; this figure serves to compare the values for the rate of nucleation and the rate of growth.

Consider next the process of edgewise growth. Growing edgewise, that is, in the direction of the lamellæ, as shown in Fig. 22, it is obviously a process of the segregation of the carbon from homogeneous austenite into carbide plates. Evidently there must be carbon concentrations set up in the neighbourhood of the moving interface, with high-carbon concentrations in front of the ferrite plate and low-carbon concentrations in front of the cementite plate, providing the necessary downhill gradient for the diffusion of carbon. This gradient must be known if the rate of growth is to be calculated. Brandt has recently solved this problem mathematically, apparently in a thoroughly satisfactory manner, assuming that the rate of diffusion of carbon in austenite does not vary with concentration.

The concentration extremes present a difficult problem. The problem is usually compared to that of the growth of a crystal from a supersaturated solution, in which case it has generally been assumed that the solution at the crystal surface has the equilibrium value of saturation ; this may require modification, for, strictly interpreted, under such circumstances no growth could occur, but the concentration at the point of growth may be very near to the saturation concentration.

This argument was applied years ago to the formation of eutectics, and in recent years Hultgren has stated it clearly for eutectoids. Hultgren extrapolated the equilibrium curves below the A_{e1} temperature, as shown in Fig. 24, and stated that this gives the limiting concentrations desired, that is, the concentration in austenite in front of the ferrite is

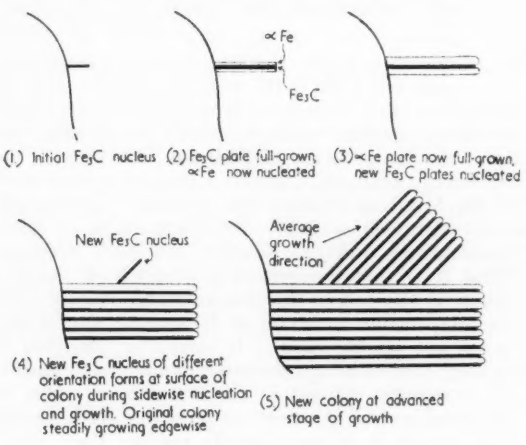

∝Fe
Fe_3C
(1) Initial Fe_3C nucleus
(2) Fe_3C plate full-grown, ∝Fe now nucleated
(3) ∝Fe plate now full-grown, new Fe_3C plates nucleated
New Fe_3C nucleus
Average growth direction
(4) New Fe_3C nucleus of different orientation forms at surface of colony during sidewise nucleation and growth. Original colony steadily growing edgewise
(5) New colony at advanced stage of growth

Fig. 20—Nucleation and growth of pearlite colonies

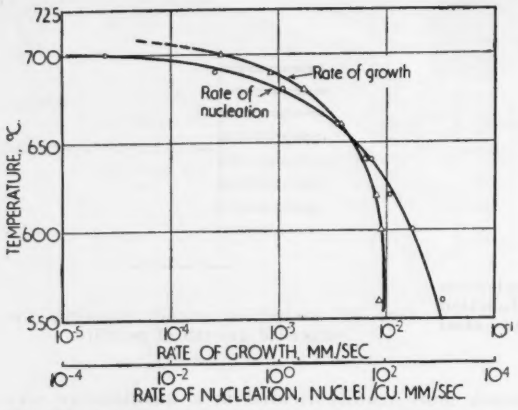


Fig. 23—Rate of nucleation and rate of growth in a eutectoid steel (0·78% carbon, 0·63% manganese, A.S.T.M. grain-size No. 5¼) as a function of reaction temperature

that given by the extrapolation of the A_3 (GS) curve, while that in front of the cementite is given by the extrapolation of the A_{cm} curve.

This is shown in Fig. 24 for a given reaction temperature; the concentration in front of the ferrite lamellæ at the temperature chosen is c_2, and that in front of the cementite lamellæ is c_1. As already suggested, the limiting concentrations may merely approach these extrapolated values as limits. Brandt assumed values of the limiting concentrations as extrapolated in calculating the rate of growth. The difference between these concentrations, and half the distance between the lamellæ—the interlamellar spacing—define the concentration gradient. This gradient and the diffusion coefficient together determine how fast carbon is delivered to the growing carbide plate and thus determine the rate of growth.

On decreasing temperature of reaction, the limiting concentrations increase, as the extrapolation shows, and the interlamellar distance decreases, both contributing to an increased rate of growth; the diffusion coefficient decreases also but not sufficiently to compensate for the first two factors, and thus the rate of growth increases as the temperature decreases.

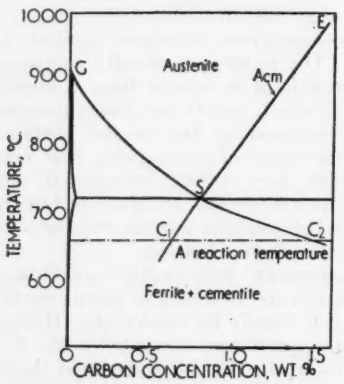


Fig. 24—Hultgren's extrapolation of GS and ES curves for iron–carbon alloys

Brandt's fundamental work may be modified by taking into account the variation of the diffusion coefficient with carbon concentration. Recently, Batz and Wells, in the author's laboratories, have extended earlier measurements on the diffusion coefficient of carbon in γ iron to high-carbon concentrations, as shown in Fig. 25. These measurements show that the diffusion coefficient is increasing rapidly as the concentration increases. If this curve is extrapolated to the extreme limiting concentrations required by the Hultgren extrapolation, it reaches high values. Introducing these values into the Brandt solution, Fig. 26, the disagreement he found at low temperatures, amounting to a lower rate than measured, is removed and the agreement is quite good. The rate of growth of pearlite in carbon steels is thus well understood.

The interlamellar spacing itself presents a basic problem. Careful measurements of the spacing as a function of temperature provide curves of the type shown in Fig. 27. The interlamellar spacing decreases as the temperature of formation decreases. It is difficult to say whether this spacing decreases linearly with temperature, or in some other way, for example, exponentially. The basic problem is: What determines the spacing? Until recently no persuasive or even attractive argument on this point has existed; however, it has recently been proposed by Zener, in a

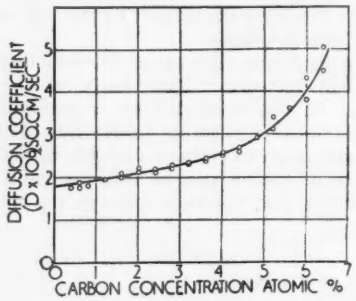


Fig. 25—Diffusion coefficient of carbon in austenite as a function of carbon concentration (temperature 1195° ± 5° C.)

very interesting paper, that the spacing is set by the free energy available in the reaction. The area of the ferrite–cementite interface in unit mass of pearlite obviously increases with decrease in the spacing; the lower the temperature of formation the greater the free energy available, and this is the energy that must be employed in creating the interface; accordingly more energy is available for this purpose at lower temperatures and the spacing can thus decrease. What it is that determines how much of the free energy is allotted to this purpose, and exactly what the temperature variation of the spacing should thus be, is not wholly clear. It might be observed in passing, that although thermodynamic measurements are extremely difficult in these reactions, owing to the smallness of the heat energies involved, precise data would be extraordinarily useful; they would remove such arguments comfortingly from the depths of speculation.

THE FORMATION OF PEARLITE IN EUTECTOID ALLOY STEELS

Alloying elements exert a complicating effect upon the pearlite reaction, leading ultimately to phenomena that are difficult to understand, even qualitatively. As to nucleation in alloy steels, it will again be assumed—and there is evidence for it—that the carbide phase, whatever it may be, nucleates pearlite. The addition of an alloying element to austenite creates a smaller probability of the chance association of atoms of the right composition to form a nucleus and, perhaps of more importance, alters the energy relationships between austenite and the nucleus. A smaller free-energy change, other factors equal, would give a lower rate of nucleation, and any special requirement of composition of the nucleus would give the same effect. Inasmuch as the carbide in alloy pearlite is usually modified cementite, or some quite different carbide, the original nucleus presumably also departs in composition from that of ordinary cementite. Moreover, since nucleation in this case also is nearly exclusively at the grain boundary, these circumstances must be considered as they apply at the grain boundary. Since the days of Gibbs, it has been known that solutes must be concentrated at boundaries if this provides lower surface energies, and conversely. While probability calculations of atom distribution might be made, little can be done concerning the question of energy changes and of surface concentrations; any argument can be only qualitative and the subject must be approached from experiment.

With the exception of cobalt, all alloying elements when in solution in austenite appear to decrease the rate of nucleation of pearlite. This conclusion is drawn from observations that are qualitative (though unmistakeable), for apart from cobalt no accurate determinations have been made; the work on eutectoid molybdenum steels by Blanchard, Parke, and Herzig, shows that molybdenum apparently decreases the rate of nucleation by a factor perhaps as large as 1000. The marked effect of chromium in decreasing the rate of formation of pearlite, especially at the lower chromium concentrations where on a percentage basis the effect is the greater, is a parallel case.

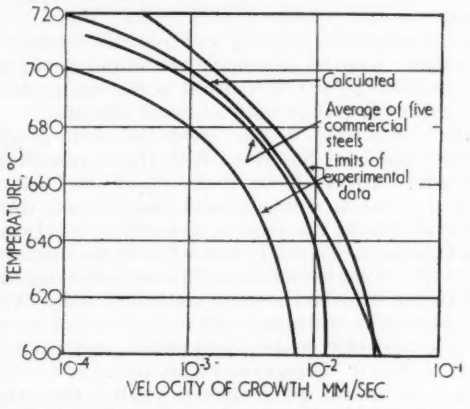


Fig. 26—Comparison of observed and calculated rates of growth of pearlite

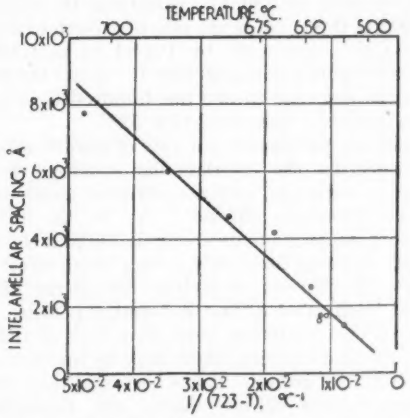


Fig. 27—Interlamellar spacing of pearlite as a function of the reciprocal of the undercooling

Measurements on molybdenum steels will shortly be available.

The case of cobalt steels is especially interesting. Hawkes made careful measurements on these steels, showing that the rate of nucleation of pearlite is appreciably increased by cobalt. Perhaps the proposal referred to later in considering growth may apply here also, that cobalt increases the free-energy change of the pearlite reaction, thus making more energy available for nucleation and thus increasing the rate; if the remaining alloying elements should have the opposite effect, their retarding effect upon nucleation would be at least in part explicable.

When the amount of the alloying element is high, a new set of phenomena appears. For example, at molybdenum contents above 0·50%, the carbide in the pearlite is no longer orthorhombic cementite, but is instead a face-centred iron–molybdenum carbide. Similar behaviour is exhibited by high-chromium alloy steels, as Lyman and Troiano have shown. Although these conclusions are drawn from studies of samples that have reacted to form substantial amounts of pearlite, it may, though perhaps not with utter certainty, be assumed that the original nucleus is also a modified carbide. The change to a different carbide must, of course, mean that the rate of nucleation of this new carbide exceeds that of cementite. If the composition of the nucleus could be predicted from the ternary equilibrium diagram the problem would be greatly simplified, but as will be seen when the growth of pearlite is considered, this is most certainly not so; the problem is one of kinetics, not equilibrium, as indeed it is throughout this whole subject.

The effect of alloying elements upon the rate of growth of pearlite is known better, and may be treated more nearly quantitatively than the effect upon the rate of nucleation; at least, the problem can be more rigorously formulated. Again except for cobalt, all alloying elements decrease the rate of growth of pearlite; many qualitative observations show this and direct measurements on manganese and molybdenum steels and semi-quantitative measurements on others have been made. In carbon eutectoid

steels, reacted at 680° C., variations in manganese from 0·2 to 0·8% cause the rate of growth to decrease to one-fifth; new work by Parcel on molybdenum eutectoid steels reacted at 650° C., shows the rate of growth to decrease to one one-hundredth as molybdenum increases from 0·02 to 0·52%.

As already mentioned, the rate of growth should be determined by the interlamellar spacing, the concentration extremes, and the diffusion coefficients of whatever elements diffuse. As to the diffusion coefficient, measurements are available that show that alloying elements have only a very small effect upon the rate of diffusion of carbon; but if the alloying element itself must diffuse in forming pearlite, then, owing to the relatively very slow rate of diffusion of the alloying element, there may be one reason for the slow rate of growth. It has been said that alloying elements cannot diffuse during the formation of pearlite, for, it is asked, why should pearlite which normally grows rapidly wait for the segregation of the slowly diffusing alloying element? The question should be answered by experiment.

The available evidence, for example, in partition studies in molybdenum steels, shows that the cementite in low-molybdenum pearlite does indeed contain molybdenum. The molybdenum content of the cementite carbide in isothermally reacted steels is in fact greater than that which can be induced into the carbide after far longer tempering of quenched steels at the same temperature, which surely argues against immediate and thus rapid molybdenum segregation just *behind* the growing pearlite interface. There is, in addition, evidence that manganese diffuses to the cementite in forming pearlite in manganese steels. It is obvious that when the carbide in the pearlite formed is a special molybdenum carbide or special chromium carbide, the diffusion of these alloying elements must occur during growth. Even if it be accepted that the diffusion of alloying elements retards the growth of pearlite, the effect of alloying elements on the interlamellar spacing, which, noted below, provides a like retardation, is also a contributing factor; the evidence is inadequate to appraise the relative contributions of these two factors.

Little or nothing can be said concerning the concentration limits in the austenite in advance of the growing pearlite interface in alloy steels, that is, the extrapolation of the solubility curves in alloy steels is wholly conjectural. Brandt's calculations, however, suggest that the effect of conceivable changes in these limiting concentrations on the rate of growth cannot be large, and it thus seems that exploration of this possibility would probably be fruitless.

The interlamellar spacing, however, presents some interesting aspects. It will be remembered that a greater spacing means a lower rate of growth, other factors remaining unchanged. At the same temperature, nickel, manganese, and molybdenum decrease the rate of growth, and correspondingly increase the interlamellar spacing, whereas cobalt, which increases the rate of growth, decreases the spacing; the decrease in spacing caused by cobalt accounts quantitatively for the increased rate of growth observed. The correlation of spacing with the rate of the pearlite reaction and presumably with the rate of growth, is close. Molybdenum has the greatest effect upon the rate of the pearlite reaction near the knee of the isothermal diagram where the effect of molybdenum on the spacing is large, and least near A_{e1} where the spacing seems unaffected; as little as 0·15% of molybdenum has a detectable effect upon the interlamellar spacing. This correlation of the spacing and the rate of growth appears to be important. Zener argues that there is reason to believe that cobalt increases the free energy of the pearlite reaction as compared to that in carbon steels, and thus provides more energy for the creation of the ferrite–cementite interface in pearlite, resulting in a decreased spacing. On this basis nickel, manganese, and molybdenum might be expected to decrease the free energy somewhat. If the comparable argument is employed in nucleation, as suggested above, nucleation and growth have some fundamental similarities.

In carbon steels, pearlite forms down to the knee of the isothermal diagram, and no farther, joining there, imperceptibly in rate, with the formation of bainite. In alloy steels, however, pearlite may form a knee of its own, that is, its rate of formation passes through a maximum as the temperature decreases, as in the cases of molybdenum steels and chromium steels. The process, of course, is still one of nucleation and growth, but there have been no measurements of the rates in such a case, nor of interlamellar spacings, though they are under way. Various suggestions have been made concerning mechanisms that will provide for a maximum in the rate of nucleation and the rate of growth at some subcritical temperature, but they lack the virtue of submitting to test. In view of the complexities in alloy steels where the phenomenon is observed, it would appear preferable at the moment to pursue the subject experimentally until the problem itself is clarified in terms of known rates of nucleation and growth.

That knowledge of equilibrium helps but little in such studies is nowhere shown more clearly than in the reactions of alloy steels. It has been observed in both molybdenum and chromium steels that the partition of the alloying element between ferrite and cementite in pearlite varies with the temperature at which the pearlite forms. Moreover, the partition coefficient when the pearlite reaction is just complete changes as this pearlite is held for long times at the same temperature, striving towards the equilibrium partition. Kinetics determine the initial partitions, not equilibrium, and of course it is this circumstance that makes the study both new and difficult.

The complexities in alloy steels that form pearlite do not cease here, however. Hitherto, in considering eutectoid carbon steels, it has been decided, on evidence, that no compositional changes occur in the austenite during the growth of pearlite, but Lyman and Troiano have recently shown that in the formation of pearlite in chromium steels, the unreacted austenite is depleted in carbon as the reaction proceeds. While the reaction is, of course, still one of nucleation and growth, evidently, in deriving kinetics, such reactions must be clearly distinguished from the more ordinary ones. It should be remarked finally, that these reactions do indeed proceed by nucleation and growth, whatever their complexities, and that an explanation

of the isothermal reaction rates, which compose the isothermal diagram, must be sought in the factors which determine the rates of nucleation and growth which themselves completely fix the isothermal rate.

HYPO-EUTECTOID STEELS

Hypo-eutectoid steels are more important, practically, than eutectoid steels, for they constitute the great bulk of all steels manufactured. Some of the principles advanced to account for the formation of pearlite may be used here, and to these must be added others that specifically apply to this type of reaction. The study of rates of nucleation and growth in hypo-eutectoid steels is still in its infancy, and must await a thorough understanding of the factors controlling morphology. It is to this latter subject that this section will be largely devoted.

The elementary features of the rate of isothermal reaction of hypo-eutectoid steels are well known. Figure 3 portrays the rates of reaction as assembled in an isothermal diagram. Hypo-eutectoid steels first reject pro-eutectoid ferrite and, at temperatures below A_{e1}, later form pearlite. The amount of pro-eutectoid ferrite decreases with decrease in temperature; in medium-carbon steels it decreases to zero or nearly zero at the knee of the curve, which is the equivalent of saying that pearlite formed at lower temperatures contains less carbon.

The formation of pro-eutectoid ferrite proceeds by nucleation and growth, but growth leads to microstructures geometrically more complex than in eutectoid steels. The isothermal rate of formation of pearlite must be treated in terms of the rates of nucleation and growth, but owing to the complex morphology of pro-eutectoid ferrite, the isothermal reaction equation cannot be so simply derived as in the case of pearlite where simple spherulites of the product could legitimately be assumed. Accordingly, it is especially important in these steels to consider morphology in attacking the question of kinetics. Carpenter and Robertson in their splendid work of nearly twenty years ago studied morphology in samples reacted during cooling. The new work here reported relates to isothermal reaction, complementing and extending the work of Carpenter and Robertson; it is largely the work of Mr. Arthur Dubé, who has been associated with the author.

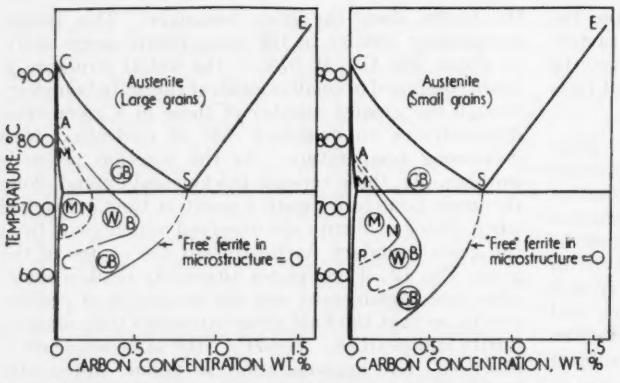
The Morphology of Pro-Eutectoid Ferrite

The morphology of pro-eutectoid ferrite is complex. It varies with temperature, carbon content, time, and austenite grain-size. Consider first the morphology of a 0·32% commercial carbon steel, reacted at different temperatures. The upper equilibrium temperature, A_{e3}, is about 795° C. and the A_{e1} temperature is about 720° C.

The reaction just under the A_{e3} temperature, as Carpenter and Robertson showed, is the formation of small ferrite crystals at the austenite grain boundaries. Figure 11 shows this steel, with an austenite grain-size of A.S.T.M. No. 7, that is, of a mean grain area of 0·001 sq. mm., reacted for 30 sec. at 725° C. In the subsequent discussion this steel will be designated as the fine-grained steel. As time goes on the reaction consists simply in the formation of new ferrite crystals, and thickening and prolongation of the ferrite along the grain boundary. This simple morphology obtains in the temperature range down to about 685° C. At 675° C. the initial structure is again composed of small crystals at the grain boundary though the greater number of these in a given time demonstrates an increased rate of nucleation with decreasing temperature. As the reaction proceeds isothermally, these crystals thicken and extend along the grain boundaries until a point in time is reached when plates of ferrite are observed which grow from the grain-boundary ferrite toward the centre of the grain, Fig. 12. These plates ultimately thicken somewhat and agglomerate, and the formation of pearlite sets in, so that the final structure shows only massive ferrite and pearlite. At 650° C. the same sequence is observed, but agglomeration is minor, apparently interrupted by the formation of pearlite which is more rapid at this temperature, and the Widmanstätten pattern, though not of high perfection, is maintained in the final microstructure. At lower temperatures the same sequence is observed, with less and less ferrite appearing, until a temperature of about 600° C. is reached, when the amount of pro-eutectoid ferrite is so small that the reaction does not proceed beyond the grain-boundary stage.

In this same steel in the coarse-grained condition, with an austenite grain-size of A.S.T.M. No. 1, that is, a mean grain area of 0·062 sq. mm., profound alterations in morphology appear. At 750° C. the familiar grain-boundary ferrite appears, outlining the grains, Fig. 13, without subsequent alteration. On reaction at 725° C. the same initial stage obtains, but this is followed by the formation of ferrite plates, which ultimately thicken. The Widmanstätten pattern in this steel thus appears at a higher temperature than in the fine-grained steel. At 700° C. the same features are shown, except that more ferrite appears, and ferrite grains have appeared within the austenite grain, Fig. 14. These grains are Widmanstätten in character and are characteristically more precisely Widmanstätten in form than the plates which grow from grain-boundary ferrite. At lower temperatures, below A_{e1}, down to about 650° C., the same sequence is observed, and as is to be expected, less ferrite appears in the fully reacted steel, for again the formation of pearlite interrupts the growth of ferrite. The total amount of pro-eutectoid ferrite formed below A_{e1} is less in coarse-grained steel than in the fine-grained steel similarly reacted, as was noted by Carpenter and Robertson on steels reacted during cooling. An explanation of this phenomenon will be given later. At 650° C. the reaction to pearlite interrupts the ferrite reaction at such an early stage that only grain-boundary ferrite forms. As the reaction temperature is further lowered, this effect increases until ferrite is no longer detectable.

Morphological sequences have also been followed in coarse- and fine-grained steels with 0·48% and with 0·62% of carbon. In the higher-carbon steels, Widmanstätten figures do not appear because of the early interruption of the reaction by the formation of pearlite. These structural results for the three steels noted are plotted in Fig. 28, which represents the final microstructures of the isothermally reacted steels. It is clear that temperature, grain-size, and



(1) Area limited by MNP: Massive ferrite formed by impingement of growing ferrite crystals previously of Widmanstätten character or of grain-boundary type
(2) Area limited by ABCMNP: Widmanstätten ferrite originated by formation of side plates of ferrite or by nucleation and growth within the grain
(3) Area limited by GABSC: Grain-boundary ferrite
Large grains: A.S.T.M. No. 0–1
Small grains: A.S.T.M. No. 7–8

Fig. 28—Diagram of morphology showing approximate limits of various types of final microstructures observed after isothermal reaction

percentage of carbon are all variables which determine the final microstructure.

Theory of Morphology

These morphological features may be in part understood. The far higher rate of nucleation at the grain boundary is similar in origin to that observed in pearlite, and the rapidly increasing rate of nucleation with decreasing temperature—for which accurate quantitative data are not yet available—is in accord with formal nucleation theory. The growth of these first crystals along the austenite grain boundaries presents a phenomenon worthy of consideration.

Figure 15 shows that the growth along the grain boundary of individual ferrite crystals is more rapid than that perpendicular to the grain boundary. It might appear that this effect originates in a more rapid rate of diffusion of carbon along the grain boundary, but this seems to be excluded, for it has been shown that the diffusion coefficient of carbon is not greater at the grain boundary. It must be remembered that the phenomenon of growth may fruitfully be considered as a process in which thin unit layers of the crystal are deposited in succession, that is, as a continuous process of two-dimensional nucleation, a subject upon which Volmer and Stranski have written. Assuming that the same principles apply to the formation of these two-dimensional nuclei as apply to the formation of three-dimensional nuclei, then such two-dimensional nuclei will form faster at the grain boundary, that is, growth will be more rapid along the grain boundary.

As noted before, the amount of grain-boundary pro-eutectoid ferrite varies with the austenite grain-size at temperatures below A_{e1}, Fig. 29. At temperatures above A_{e1} the total amount of pro-eutectoid ferrite does not vary with grain-size, for it is determined by equilibrium alone. Just below A_{e1}, both grain-boundary ferrite and Widmanstätten ferrite may appear, but the amount of grain-boundary ferrite per unit volume is greater in the fine-grained steels. At quite low temperatures, where Widmanstätten ferrite disappears, the thickness of the envelope at each grain boundary is approximately the same in the coarse- and fine-grained steels, with the result that the total amount of ferrite per unit volume in the fine-grained steel is the greater.

Thus at high temperature, grain-boundary ferrite alone appears; as the temperature of reaction is lower, Widmanstätten ferrite appears, growing as plates from the grain-boundary ferrite; and at still lower temperatures ferrite plates form by nucleation and growth independently within the crystal. Although these Widmanstätten figures have long won the attention of metallurgists, since the days of Sorby, the mechanism has not yet been wholly clarified.

A comparison of the behaviour of coarse- and fine-grained steels is instructive. At the same high temperature Widmanstätten figures will be observed in the coarse-grained steel and not in the fine-grained. The thickness of the ferrite plates is characteristically large at high temperatures; indeed, in the case cited, the spacing of the plates in the coarse-grained steel is greater than the grain diameter itself of the fine grains. It seems that ferrite plates cannot appear as a family of parallel plates in the fine-grained steel because the grain diameter is less than the inter-plate distance; such a steel cannot display the Widmanstätten structure.

The spacing of the ferrite plates appears to be quite fundamental. It recalls the spacing between the arms of dendrites, and may well originate in a similar way, modified by the presence of the austenite grain boundary and by the requirement that growth be along the octahedral plane of the austenite. As in the case of dendrites, the inter-plate distance decreases as the temperature of growth is decreased. In this view, growth proceeds along the grain boundary with a natural tendency to develop crystal faces, and thus edges and corners. Such edges and corners become points at which growth tends to develop preferentially owing to the point effect of diffusion, an effect analogous to the thermal-point effect in heat flow. At high temperatures, where growth is slow and the

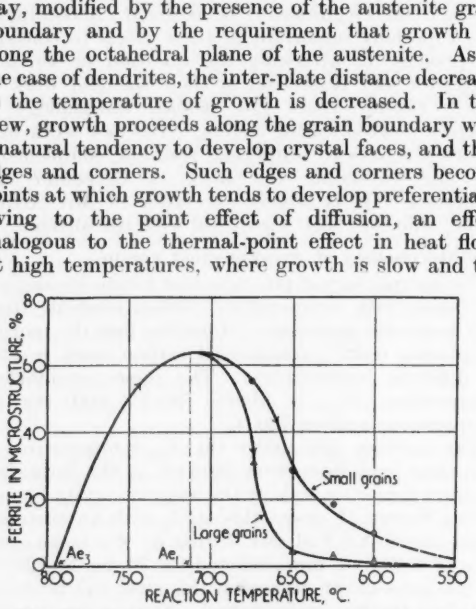


Fig. 29—Variation of the percentage of ferrite formed in a hypo-eutectoid steel as a function of reaction temperature

rate of diffusion rapid, there is time for the equalization of the carbon concentrations between such points and the centre of crystal faces, but at lower temperatures the rate of growth is fast and the rate of diffusion is slow, and equalization is inadequate, with the result that edges develop and these grow into plates. This will occur periodically during growth, with a resultant spacing determined by how large the crystal may grow before the point effect becomes dominant, and a plate develops. As the temperature decreases, thus so will the spacing. In the case of dendrites, growth is in the direction of a major crystal axis. These plates grow most rapidly along the octahedral planes of the austenite ; owing to the orientation relationship subsisting between the ferrite and the austenite, growth is thus most rapid in a direction lying in the dodecahedral plane of the ferrite, and least rapid in the direction normal to the most densely packed lattice plane. This appears to be a form of the familiar law of Bravais, originally stated for crystals forming from liquid solutions.

The occurrence of ferrite plates independently formed within the grain is obviously a nucleation and growth process of no unexpected characteristics. As in the case of pearlite, the rate of nucleation within the grain is not nil, it is merely very much smaller ; given a sufficient time, nuclei will appear within the grain also.

It has been shown that the thickening of grain-boundary ferrite proceeds parabolically with time. This rate of growth is about the same in both the coarse- and the fine-grained steels ; thus, in the coarse-grained steel, more time is available for intragranular nucleation. This reasoning is of the school of Belaiew, and experiment seems to substantiate it.

The curves in Fig. 28 show that the tendency to form Widmanstätten figures decreases at low temperatures. This results from the competitive nature of the two reactions, austenite-to-ferrite and austenite-to-pearlite, as a consideration of the rates of nucleation and growth of the two reactions will show.

The rate of nucleation of pro-eutectoid ferrite increases as the temperature decreases, and may actually pass through a maximum in low-carbon steels or alloy steels. This nucleation is thus entirely similar in principle to that of pearlite, but the rate of growth cannot be considered so very simply as in that case. In pro-eutectoid ferrite the concentration of carbon

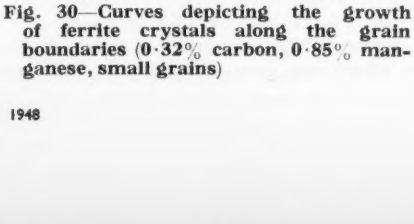
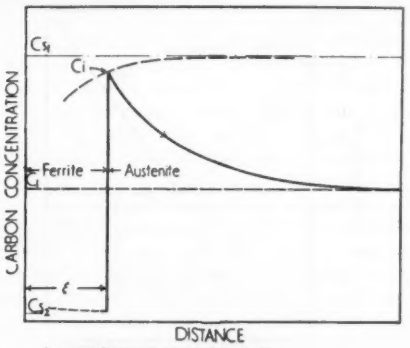


Fig. 30—Curves depicting the growth of ferrite crystals along the grain boundaries (0·32% carbon, 0·85% manganese, small grains)



ξ —Thickness of ferrite plate
Cs_1—Equilibrium concentration in austenite
Cs_2—Equilibrium concentration in ferrite
Ci —Interface concentration
C_i —Initial concentration

Fig. 31—Diagram of the carbon concentration in front of an austenite–ferrite interface

in the unreacted austenite is not unchanging during the reaction, but instead is increasing ; the boundary conditions are thus changing during growth.

There are two types of initial growth : the growth along the austenite grain boundary, and the growth perpendicular to the grain boundary. The rate of growth along the grain boundary has been measured, as shown in Fig. 30, and appears initially not to vary with time, but after a certain period it decreases. The initial, essentially constant, rate is maintained proportionately for a longer time at lower reaction temperatures.

The rate of growth perpendicular to the grain boundary, that is, the rate of thickening of the grain-boundary ferrite, is hard to measure, owing to uncertainty in the angle with which the plane of polish intersects the ferrite crystal. But the rate can be calculated, presumably on sound principles. The concentration of carbon in the austenite just ahead of the thickening ferrite plate must follow the type of curve shown in Fig. 31, which is for an infinitely large austenite grain, and will not apply strictly when the concentration at the centre of the grain changes appreciably. At the outset, when grain-boundary ferrite first forms, the concentration of carbon in the austenite at the interface immediately approaches the concentration demanded by the extrapolation of the GS curve, and thus the carbon-concentration gradient is initially exceedingly great, the rate of diffusion of carbon away from the interface is correspondingly great, and the initial rate of growth is therefore great. This may be seen in Fig. 32, where the composition of the steel is given by the perpendicular X, and the concentration of carbon in austenite at the interface is given by the extrapolation of the GS curve. But as time goes on, the gradient in the austenite diminishes ; analysis shows that this provides a parabolic rate of growth, that is, the rate of growth is inversely proportional to the thickness of the ferrite layer. This applies at all temperatures. Although the calculated rate of growth is difficult to substantiate quantitatively, observation does show that the rate of thickening falls off rapidly with time. It will be observed that the parabolic law

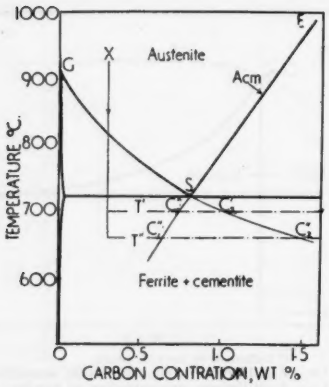


Fig. 32—Diagram showing the variation of supersaturations with respect to ferrite and cementite as a function of reaction temperature

of thickening is derived for an infinitely large grain, but when, in a small real grain, the carbon concentration at the centre of the grain decreases, the rate of growth must correspondingly decrease.

The parabolic rate constant, however, increases as the temperature falls, for the increasing supersaturation, shown by the extrapolated GS curve, provides a greater concentration gradient, and to a degree sufficient to offset the diminished diffusion coefficient. The rate of growth is a resultant of these two factors, the increasing supersaturation and the decreasing diffusion coefficient. This provides a maximum in the rate of growth at a low temperature when the decrease in the coefficient of diffusion is sufficient to overtake the increase in supersaturation. Such maxima are in fact observed in low-carbon hypo-eutectoid alloy steels where pro-eutectoid ferrite forms at all temperatures, above and below the pearlite knee.

In the discussion of pearlite, the fundamental importance of the ratio of the rate of nucleation to the rate of growth, was commented on, noting that it increased greatly with decreasing temperature, giving more and smaller pearlite nodules ; a wholly similar behaviour is observed here, a larger number of smaller ferrite grains occurring at lower temperatures.

The Pearlite Interruption

The question of why the formation of pearlite interrupts the growth of grain-boundary ferrite at an ever-earlier stage as the temperature of reaction is lowered, now needs to be considered. The growth of ferrite, and the nucleation and growth of pearlite are competitive reactions ; both the rate of growth of ferrite, and the rates of nucleation and growth of pearlite, increase as the temperature is lowered, but the latter increase more rapidly than the rate of growth of ferrite, and the formation of pearlite thus interrupts the growth of ferrite at a proportionately earlier stage.

As already stated, the rate of thickening of ferrite can be calculated as a function of the temperature, from the variation of the supersaturation and the variation of the diffusion coefficient with temperature. The supersaturation of the austenite with respect to ferrite is given by the extrapolated GS line in Fig. 32, and with respect to cementite by the extrapolated SE curve. At the interface, where the concentration in the austenite is high, obviously the supersaturation for cementite is high, but at a distance toward the centre of the grain this supersaturation becomes less. Thus the respective supersaturations for cementite and ferrite in the matrix austenite are again given by the extrapolated solubility curves. High supersaturation for cementite implies the imminent precipitation of cementite. It is important to note that this supersaturation is greater than for the nucleation of pearlite in a eutectoid steel, and increases more rapidly as the temperature falls, so that presumably the rate of cementite nucleation does also. Whenever a cementite nucleus forms, pearlite will be nucleated, and the problem of the pearlite interruption is thus the problem of the nucleation of cementite.

The probability of forming a nucleus is proportional to the rate of nucleation and to the time available for nucleation. When grain-boundary ferrite first begins to form, the ferrite–austenite interface is moving rapidly, that is, there is not much time for nucleation. As the rate of growth falls off with time, the probability becomes greater, and ultimately a cementite nucleus forms. Once pearlite is nucleated by this cementite, it grows at a characteristically high rate as compared to the rate of thickening of the ferrite at the grain boundary ; starting in the austenite contiguous to the ferrite where the carbon concentration is high, the cementite plates are thick, Fig. 16, and as growth continues into lower carbon areas, the cementite plates become thinner.

It can be shown from these considerations that the thickness of the ferrite at which the nucleation of pearlite interrupts further ferrite growth, decreases as the temperature decreases. This interruption of the growth is obviously the factor which prevents the formation of Widmanstätten plates at low temperatures. The interruption of the thickening of the ferrite at an increasingly earlier stage on decreasing temperature probably occurs because the supersaturation at the interface at low temperature becomes so large that the cementite nucleus may form even though the thin grain-boundary ferrite grows at a rate which is characteristically high. It will thus be obvious that the value of the supersaturation at the interface, and the velocity of the thickening of the ferrite grain-boundary layer govern the point of interruption by pearlite nucleation, affording a critical thickness of the ferrite layer at each reaction temperature ; this critical thickness will be the same in steels of different grain-sizes, providing more ferrite per unit volume in the fine-grained steel than in the coarse-grained steel. In steels of different carbon contents, and at different temperatures, the carbon composition of pearlite thus changes, and the rate of growth changes. Measurements of the rate of growth of pearlite in steels with 0·32% and 0·62% of carbon, respectively, show that the rate of growth is the greater the lower the carbon content ; this is entirely in accord with Brandt's calculations.

The isothermal rate curve for this process is in two parts, representing successive reactions. In the early stages, where only grain-boundary ferrite forms, such

curves can be calculated, employing a rate of nucleation and a rate of growth decreasing parabolically with time, but when Widmanstätten ferrite forms, the geometry becomes very complex, and the reaction rate equation also. The second stage, when pearlite forms in a matrix interlaced with ferrite plates, is similarly complicated geometrically, for this ferrite hinders the growth of pearlite, providing steric hindrances resulting in a much slower rate. This steric factor thus affects the pearlite rate to the degree that the pro-eutectoid ferrite forms plates.

It is implicit in the foregoing that the ferrite and the pearlite reactions must overlap to some extent, that is to say, ferrite continues to form at one point for a while after pearlite has already started to form at another point. The nucleation of pearlite following the formation of ferrite is a nucleation phenomenon, and thus governed by probability. If ferrite thickened with utmost precision, forming no protuberances, providing a ferrite–austenite interface wholly plane, the initiation of the pearlite reaction would be governed by probability alone, providing a certain small degree of overlap, but this is augmented by the variations in concentrations in the austenite resulting from irregular ferrite growth. The degree to which overlapping occurs has not been studied systematically.

Recent work has shown that hypereutectoid alloys behave similarly in many respects. Similar rules appear to apply to the nucleation and growth of the grain-boundary phase, and of the Widmanstätten figure, but cementite plates grow from grain-boundary cementite only infrequently, and Widmanstätten precipitation by separate nucleation and growth within the grain is far more pronounced, forming a sharply defined Widmanstätten figure of thin long plates.

PRO-EUTECTOID REACTIONS IN ALLOY STEELS

Pro-eutectoid reactions in alloy steels, *i.e.*, the formation of pro-eutectoid ferrite and pro-eutectoid cementite, show many similarities to the corresponding reactions in carbon steels. The reaction is again a nucleation and growth process, the pro-eutectoid constituents forming preferentially at the austenite grain boundaries, the ratio of the rate of nucleation and growth increasing as the temperature of reaction is decreed, as and Widmanstätten figuresagain appearing. Although these generalizations are quite justified,there have been no careful studies on morphology and none on rates of nucleation and growth ; only scattered photomicrographs and measurements of the overall reaction rate are available. The addition of alloy may well modify both morphology and rates of nucleation and growth, for obviously the diffusion phenomena are more complex, the possibility of concentration of the alloying element at the austenite grain boundary appears here again, and the interface energies must be altered ; these factors must affect both morphology and rates. The field is open for definitive study.

It was observed in considering alloy eutectoid steels that in some steels pearlite forms both above and below the pearlite knee ; such alloy steels differ in this way from carbon steels and from nickel and manganese alloy steels in which pearlite forms only at temperatures above the knee. This behaviour of pearlite in alloy eutectoid steels has its counterpart in pro-eutectoid ferrite in low-carbon alloy steels, ferrite forming at temperatures both above and below the temperature of the knee, and when the carbon is sufficiently low, exhibiting a knee of its own. This knee, as in the case of pearlite, must indicate a maximum in the rate of nucleation or in the rate of growth, or both, and may find its explanation in the competitive processes of free-energy change and diffusion rates, a possibility anticipated in formal nucleation theory. Measurements of these rates are necessary before the problem can be formulated.

The phenomenon of a ferrite knee in the isothermal diagram is exhibited by alloy steels in which the alloying element is carbide-forming, for example, chromium, and these steels constitute a class in this respect. Other alloy steels, as exemplified by nickel steels, form a second class, in which the alloying element does not change the form of the isothermal diagram, but merely displaces it to longer times. In such steels pearlite forms only at temperatures above the knee. The correlation of this behaviour with the carbide-forming propensities of the alloying element is good, but the basic reason for the distinction of the two classes of steels has escaped formulation.

It would be comforting if full and satisfactory knowledge of the equilibrium constitution of alloy steels were available, for this would provide some foresight into the phase constitution to be expected, and would illumine departures from equilibrium as determined by kinetics, but information on the constitution of even the ternary systems of iron is very limited, and it is usually impossible to define the final equilibrium state.

Although but little work has been done on the composition of pro-eutectoid ferrite in alloy steels, beautifully executed work by Bowman on hypo-eutectoid molybdenum steels has shown that pro-eutectoid ferrite in these steels contains exactly the same concentration of molybdenum as the austenite from which it forms, *i.e.*, molybdenum does not diffuse during the formation of ferrite. In view of this surprising though well-attested result, it is difficult to understand why molybdenum, like all other alloying elements, retards the formation of ferrite. Blanchard and others believed that the slight effect of molybdenum in decreasing the rate of diffusion of carbon might be the cause, though this hardly seems adequate, or that molybdenum might change the limiting concentrations in such a way as to decrease the diffusion gradient, or, finally, that molybdenum might actually retard the fundamental γ–α transformation, *i.e.*, that the interface reaction itself, apart from diffusion, might in this case be rate-determining. The subject is difficult to pursue at this time, for apart from these molybdenum steels, there is little useful information ; much more work on other systems, with the same end in view, is greatly needed.

Observations on the effect of the rejection of pro-eutectoid constituents upon the subsequent rate of formation of pearlite, show that molybdenum not only retards the formation of ferrite, but also so alters the kinetics of the system that the pearlite reaction interrupts the growth of ferrite at a later time, that

is, molybdenum increases the amount of pro-eutectoid ferrite. The same effect has been observed by Lyman and Troiano over the entire carbon range in chromium steels. Pro-eutectoid cementite in molybdenum steels has the opposite effect. In this case cementite actively nucleates pearlite, for which it is a natural inoculant, thus decreasing the time for initiation of the formation of pearlite, and grain boundaries do not play their usual rôle in controlling the number of nuclei formed. In all such successive reactions, kinetics are still determined by nucleation and growth, but when the pro-eutectoid constituent forms plates, the subsequent pearlite grows with continued hindrance, the steric factor again being prominent. A reaction-rate equation would have to be written with this steric factor properly included.

Alloying elements may thus produce a ferrite knee in the isothermal diagram, which anticipates a pearlite knee occurring at the same temperature, with both ferrite and pearlite forming at temperatures both above and below the knee, as with the steel containing 1% of chromium and 0·4% of molybdenum studied by Klier and Lyman. Whereas in carbon eutectoid steels pearlite forms only at temperatures down to the knee of the isothermal diagram, and bainite below, in the class of steels exemplified by chromium steels, pro-eutectoid ferrite forms below the knee of the pearlite curve, down to the region where the X constituent and bainite form, providing an intermediate temperature at which the rate of reaction is very slow, Fig. 5. It is proper now to consider the complex case of bainite.

BAINITE

Below the point of the knee of the isothermal diagram in eutectoid carbon steels, and in alloy steels in the region of the " bay " in the isothermal diagram, new products of the decomposition of austenite appear, differing fundamentally in nature from pearlite. These structures, which will be referred to by the generic term " bainite," and which are formed at intermediate or low temperatures, are by no means new, for they were observed early in this century.

The structures are simplest as they occur in eutectoid carbon steels. As formed at high temperatures, Fig. 17, the structures are coarser than low-temperature pearlite—that which used to be called nodular troostite. The progress of the transformation appears to be the thrusting of thin fingers of ferrite into the austenite matrix, followed by the precipitation of carbide, providing a feathery structure. As Hultgren pictures it, Fig. 33, ferrite forms first, momentarily enriching the austenite locally in carbon to a point where carbide precipitates in particles, with ferrite growing between. The ferrite plates grow large because of the relatively high rate of diffusion of carbon and the relatively low value of the rate of nucleation of the cementite. As the temperature of isothermal decomposition is lowered, the structure changes gradually until reaction just above the martensite point produces a dark-etching acicular structure difficult to distinguish from tempered martensite, Fig. 18.

These structures have proved difficult to study. Observations by G. V. Smith indicate that both the number and the size of bainite patches in the resultant structure increase as the reaction proceeds, clearly suggesting a nucleation and growth process, and suggesting an attack similar to that employed on pearlite, the measurement of the rates of nucleation and growth. Nothing has been done in this direction, as this part of the study of the fundamentals of the decomposition of austenite, like the rest, received but little attention during the war years.

If it is assumed, on the slight evidence that exists, that bainite does form by nucleation and growth, rather than, as in the case of martensite, by shear, the alternative process, then it becomes evident immediately that the morphology of the product imposes special steric factors: the advancing front, Fig. 17, is not plane and the reaction is not consummated at that interface, and the structure frequently shows interlacing, so that the overall rate of decomposition, though fundamentally dependent upon rates of nucleation and growth, can be calculated from these only by a very complex and possibly fruitlessly complex formulation. The problem is therefore not unlike that in the formation of pro-eutectoid ferrite, where the geometrical complexity in the disposition of the reaction product makes analysis of reaction kinetics difficult. In the case of high-temperature bainite (and in many alloy bainites) the structures formed are exceedingly similar to those in pro-eutectoid ferrite. Bainite forming along austenite grain boundaries throws plates of ferrite toward the centre of the grain, and these plates appear to be mere outgrowths from the grain-boundary ferrite. This behaviour is never seen in martensite structures.

Nucleation and Kinetics

The best evidence on the question of nucleation is crystallographic. The relationship between the orientation of the ferrite in bainite and the austenite from which it forms in eutectoid carbon steels is identical with that observed when ferrite is known to nucleate directly from austenite, as in the formation of pro-eutectoid ferrite in hypo-eutectoid steels, as G. V. Smith showed. The conclusion seems inescapable that the active nucleus in the formation of bainite is ferrite ; in this way the bainite reaction is to be distinguished fundamentally from the pearlite reaction.

These orientation relationships between ferrite and the parent austenite are observed throughout the temperature range in which bainite forms ; the orientation relationship subsisting between two lattices in space, and the plane in austenite to which the reaction product in the form of plates is observed to lie parallel, are to be clearly differentiated. This plane, the composition or conjugate plane, varies throughout the temperature range even though the orientation relationship remains constant. The phenomena of growth are in truth often complex, and in this case wholly unrationalized.

Although there is no supporting evidence, it has been assumed universally that the ferrite nucleus in the formation of bainite is ferrite supersaturated with carbon, presumably because the ferrite which forms precedes in point of time the formation of cementite. This supersaturated ferrite is conceived as ephemeral,

precipitating carbide very quickly ; the argument is awkward, for it is surely not proof, and a direct experimental attack, difficult to conceive, would be very welcome.

In eutectoid carbon steels the pearlite reaction, proceeding more and more rapidly as the temperature decreases, is replaced at the knee of the isothermal diagram by the formation of bainite, which forms more and more slowly as the temperature decreases. The knee of the isothermal diagram is thus a point where one reaction is replaced by a fundamentally different one. There is no sensible break in the isothermal diagram at this point in eutectoid carbon steels, as one might expect. Presumably, extremely precise measurements would show a discontinuity ; some overlap of the two reactions is always observed with samples reacted just at the knee showing both pearlite and bainite, but how much of this is to be ascribed to austenite heterogeneity is unknown. However, in some alloy steels, those in which the alloy is strong in carbide-forming proclivity, the separation of the two processes is very evident. The isothermal diagram for many alloy steels shows, as noted above, a full knee for the pearlite reaction, and a second, lower knee for the bainite reaction, separated by a bay of extremely slow reaction.

Although other proposals have been made, it seems most likely that the cessation of the pearlite reaction is brought about by the intrusion of the faster bainite reaction. This argument is a little, though not wholly, truistic. To develop it would require better knowledge of the true nature of the nucleus, whether supersaturated ferrite or not, and a sustaining knowledge of the factors which determine the rates of nucleation and growth for both pearlite and bainite, and how these might be modified by alloying elements. Here, again, existing knowledge is nearly uselessly rudimentary. Zener has proposed that the upper temperature limit of bainite, the temperature below which bainite can form, is determined by the free-energy change accompanying the formation of a ferritic phase of the same composition as the original austenite,

Fig. 33—Hultgren's model for the formation of bainite

though there have been some objections to this. The formation of martensite he considers is quite similar, except that in this case additional free energy is required, and thus a lower temperature, in order to overcome the accompanying strain energy.

Bainite in Alloy Steels

The formation of bainite in alloy steels presents a diversity of phenomena that is perplexing. This field, of the intermediate temperature transformation products in alloy steels, is very important practically, for these products occur widely in heat-treated steels. The lack of knowledge can be ascribed to several circumstances : the fundamental kinetics of nucleation and growth are but embryonic ; experimentally the microscope has been relied upon too much—a greater diversity in the experimental attack on the problem is needed ; and the work done has not been systematic enough—too many miscellaneous unrelated steels have been studied, though this is not true of the work on chromium steels and molybdenum steels. Little can be said on this subject beyond relating several of the simple features which are well attested.

The low-temperature bainite knee in many alloy steels is attended by the initial rejection of a ferrite-like constituent, usually acicular in character, which has been called the " X constituent," Fig. 19, and which is sometimes also referred to as bainite, probably inadvisedly. The formation of this constituent is well illustrated in silicon steels. It has been believed that this structure when first formed is ferrite supersaturated with carbon, but its nature is not well understood, and the relationship of this structure to bainite formed at similarly low temperatures in other alloy steels also is not understood. In 3% chromium, 0·38% carbon steels, Lyman and Troiano observed a bainite to form at 490° C. at nearly zero time, but that only 10% of the austenite reacted to this constituent, the reaction then nearly stopping, succeeded in time by the formation of pearlite. At 450° C. this reaction again starts at nearly zero time, but proceeds to 80% of completion, whence the remainder of austenite forms pearlite. This temperature dependence of the reaction to bainite suggests the similar behaviour of martensite, but the analogy should not be forced, for the bainite reaction proceeds isothermally with time, whereas martensite does not form isothermally.

Hultgren's fine paper illustrates many of the phenomena and therefore the complexities of the alloy bainites. Arguing that high-temperature products in the pearlitic region are close to equilibrium, with both carbon and alloying elements migrating, and that in martensite neither carbon nor alloying element migrates, he believes that at intermediate temperatures products should form from which carbon has migrated but not the alloying elements. The high-temperature products he designates as ortho-constituents and the low-temperature products as para-constituents. He observes, indeed, that the carbides formed in the bainitic range are not at equilibrium as shown by residue analysis, for example, a 3% manganese, 0·52% carbon steel provides a bainitic carbide of the same composition in manganese as the austenite from which it formed. Assuming from this that bainitic ferrite is similarly far from equilibrium, that is, much too high in manganese, he conceives bainite as constituted of para-ferrite and para-cementite.

Although the evidence is scanty, the suggestion is important, for the phenomena of variations in composition of both the reactant austenite and the resultants ferrite and carbide are important and frequently inscrutable. The difficulty in this matter is chiefly the lack of weighty evidence, and the difficulty of getting it, and as much the lack of knowledge of true equilibrium in these polycomponent systems. Griffiths, Allen, and Pfeil, in two admirable papers, published by this Institute, under the sponsorship of the Alloy Steels Research Committee, of which

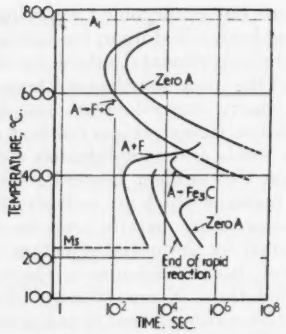


Fig. 34—Isothermal transformation diagram for a 0·69% carbon, 3% chromium steel (Lyman and Troiano)

Dr. Hatfield was Chairman, studied many of these questions, observing that austenite grain-size has but little, if any, effect upon the rate of formation of bainite.

The complexities in behaviour which are encountered in the bainitic reaction are somewhat awesome. Lyman and Troiano, studying a 3% chromium, 1% carbon steel reacted in the range from 350–450° C., observed that the reaction proceeds by separate carbide, ferrite, and pearlite reactions, and that cementite plates may form after partial decomposition to bainite, while Hultgren, working with a 5% manganese, 0·63% carbon steel, found pro-eutectoid ferrite to form above the pearlite knee, and pro-eutectoid cementite below. Morphology also is complex : Hultgren observed in a steel with 2·4% of manganese and 1·02% of carbon that on reaction at 500° C. cementite plates are formed, and then bainite, with the carbide from the bainite attaching itself to the primary carbide, producing a degenerate bainite. Blanchard, Parke, and Herzig, observing the behaviour of a 0·77% molybdenum steel reacting at 538° C., noted that the primary reaction is the formation of ferrite in plate form lying parallel to the octahedral Widmanstätten plane, and that this reaction is followed by the formation of cementite in plate form lying parallel to its Widmanstätten plane. Lyman and Troiano observed that the sequence of reactions at a low temperature in a 3% chromium, 0·69% carbon steel, is the formation of ferrite followed by a rejection of cementite, and this in turn is followed by the formation of pearlite at 450° C.; and bainite, followed by cementite, and this in turn by pearlite at 400° C., Fig. 34.

The complexities in bainite, and the lack of basic, guiding ideas, but illustrate in a magnified way the needs in this whole field. The phenomena in this field for which only a beginning in understanding has been made, are of basic importance to the iron and steel industry, and although the discussion bears the guise of science, the matters discussed are in the ultimate view practical in nature, for they underlie practice in the handling of steels. Experiment in this field should be more systematic in nature. It would be better, the author believes, especially in forwarding a knowledge of bainite, to take one ternary alloy steel for study, and to determine the equilibrium relationships with great care ; to study the morphology of the products, and particularly to attempt to correlate the morphology of pro-eutectoid ferrite with that of bainite ; and to study the composition of the separate constituents, so that the enrichment of one phase at the expense of another may more nearly be defined.

This latter point is important : a general method for the study of the constitution of micro-constituents is still lacking ; the chemical analysis of carbides by residue, a partial solution, is unsatisfactory, and has been very little forwarded in recent years. With proper attention to electrochemistry and with less conservatism in the selection of reagents for chemical attack, marked advances are surely possible ; but some more general method also is needed to study the composition of constituents. If the use of radio-isotopes can be developed for determining the partition of an element between two constituents in structures that require high magnification for their resolution, then marked progress could be made.

Morphology, in part determined by kinetics and in part determining kinetics, ought to be correlated with the great body of chemical information on the nature of crystal growth. The opportunities of cross-fertilization in this field, as in kinetics, are apparently great. Nucleation theory is patently a branch of the general field of kinetics, and ought to be developed as such a branch ; it needs to be extended toward a greater degree of reality in application to solid–solid reactions, and what is needed in this is the measurement of energies at phase interfaces, and, just as important, a general and direct attack upon the thermodynamics of these reactions, particularly a method of determining the free-energy changes that accompany the many complicated reactions which are encountered. The metallurgist brings very real talents to bear on these problems, and with further attention to fundamentals he should engage himself in the quest of converting this ancient art of heat-treatment to a new science.

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A Study of the Hydrogen, Oxygen, and Nitrogen Contents of Foundry Pig-Iron

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SYNOPSIS

The results are summarized of a survey of the residual contents of hydrogen, oxygen, and nitrogen in samples of foundry pig iron from a number of British sources. In the majority of cases the samples were provided by the makers from recent stock ; in other cases the specimens were cut from irons taken from stock piles in the hands of users. A comparison was also made between recently cast pig iron and iron samples of similar grade, but cast 25 years previously, from the same manufacturer. The gas determinations were made by the well-established vacuum-fusion method, and substantial differences in hydrogen, oxygen, and nitrogen contents were recorded with the various types of pig iron. Compositions of the irons were determined by chemical and spectrographical analysis with special attention to the residual or minor elements present.

THIS study is concerned mainly with a survey of the residual contents of hydrogen, oxygen, and nitrogen, determined by the vacuum-fusion method of different types of British foundry pig irons. In addition to the gas contents the opportunity was taken to determine the compositions of the specimens both by chemical and by spectrographic analysis, attention being given to the amounts of trace or residual elements present in addition to those normally estimated for foundry purposes.

In the majority of cases the samples have been provided by the makers, and have been selected presumably from stock piles. The actual determinations of the gas contents of these specimens have been made several weeks after the delivery of the specimens to the laboratory. In other cases the specimens were selected from stock piles in the hands of users, and the age of the specimens is not known. The opportunity arose to examine a complete range of specimen fractures of a typical foundry iron prepared in 1945, and to compare the results with a similar set of fractures of the same brand of iron which had been retained in a show-case for a period of 25 years.

The results quoted in this paper were obtained in every case from authentic samples of pig iron, and they are in most instances the mean of two or more estimations. Only on one occasion, however, has more than one pig-iron sample of each type been examined.

VACUUM-FUSION APPARATUS AND METHOD

Apparatus

The residual gas content of the pig irons was determined by the vacuum-fusion gas-analysis apparatus shown diagrammatically in Fig. 1. This apparatus was in the main similar in type to the equipment described by H. A. Sloman.[1] Apparatus for the estimation of gases in metal has often been described in the literature, and it is proposed here merely to give a very brief description of the present apparatus with a mention of points of special interest to the analysis of pig iron.

The graphite crucible in which the specimens were melted was thermally insulated from the water-cooled silica furnace tube by 150–200-mesh graphite powder. Rapid out-gassing of the apparatus prior to analysis

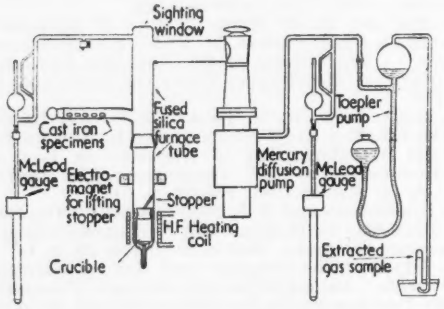

Fig. 1—Diagram of essential details of vacuum-fusion apparatus

was ensured by keeping the volume of graphite parts to a minimum. In the modified design of the crucible, shown in Fig. 2, a minimum weight of graphite was aimed at which substantially reduced the time required for degassing and was adopted to promote quick working of the apparatus. The crucible was heated by induction from a 15-kVA. spark-gap set.

The gas evolved from the specimens during fusion was pumped away by an Edwards type-7 two-stage mercury-diffusion pump and was collected in a Töpler pump of 1-litre bulb capacity. A rotary mechanical pump, Edwards Speedyvac type 2, served as a backing pump. The ultimate pressure in the apparatus was

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measured by a McLeod gauge, reading from 0·00001 to 0·01 mm. The gas collected from each specimen was stored for analysis in an inverted test-tube over mercury.

A modified Ambler apparatus (Fig. 3), normally of 5–20 c.c. was employed for the analysis of the gas sample. This apparatus differed from the orthodox Ambler apparatus by having a very large three-way tap, shown in Fig. 3. The correct manipulation of this single tap enabled the gas analysis to be conducted rapidly without the general fouling of capillaries with the reagents which is otherwise liable to take place with this type of apparatus.

The vacuum-fusion apparatus was out-gassed prior to analysis at a temperature of 1800° C. for 7 hr., followed by 2000° C. for 1 hr. It was not possible to out-gas for the whole period at 2000° C. owing to the formation of a graphite film on the sides of the silica furnace tube during prolonged heating at this temperature. When out-gassing was completed, usually signified by a rapid improvement in the quality of the vacuum, a blank was run at the working temperature of 1550° C. A satisfactory blank was 0·3 ml. of gas per hour, which when analysed yielded over 95% of hydrogen. If nitrogen were present in the blank a leak was suspected.

The time required to pump away the gases evolved from an average cast-iron specimen of 15–20 g. was 20 min. at the working temperature of 1550° C.

Sampling of Pig Iron for Vacuum Fusion

A convenient specimen for vacuum-fusion gas analysis consists of a " slug " approximately $1\frac{1}{4}$ in. long × $\frac{3}{8}$ in. dia. This sample was conveniently

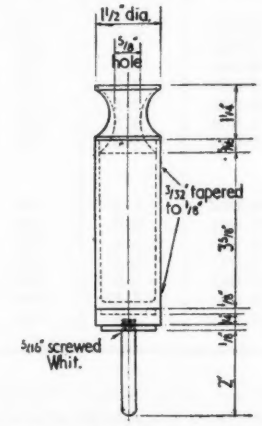

Fig. 2—Graphite crucible for vacuum-fusion analysis

trepanned from the pig iron by means of a hollow core drill. The core drill was only of value with soft, fine-grained irons; if the pig iron was coarse in structure the core tended to crumble during drilling; if the iron contained free cementite the drill rapidly became blunted.

With coarse-grained graphitic iron the best method of sampling was to saw a slice from the cross-section of the pig and afterwards saw from the slice by hand

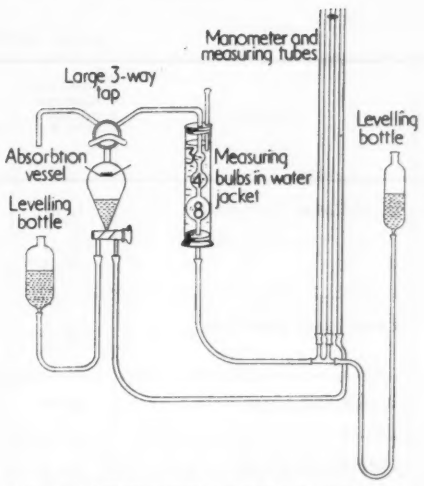

Fig. 3—Diagrammatic sketch of modified Ambler gas-analysis apparatus

a piece of approximately the correct size. The specimen was then ground to a cylindrical shape, by hand, on a small bench grinder. A " white " hard pig was most conveniently cut by means of an emery slitting wheel. The specimen, sliced roughly to shape in this manner, was finally finished by hand-grinding as before. Whatever cutting method was used in the sampling of pig iron for gas-content determination every care was taken to avoid heating.

The correct position from which to take the sample from the pig iron was the subject of experiment. It was of vital importance to avoid the silica-rich casting skin and any slaggy inclusions which would give spurious " oxygen values." The method finally adopted was to take as a standard sampling point a position along the longitudinal axis approximately central between the notches. This sampling position corresponded fairly accurately with that from which drillings for chemical analysis are taken by one of the accepted standard methods recognized by the British Cast Iron Research Association.[2]

It is important that grease and oil should not be used to facilitate the cutting of gas samples from pig iron, or considerable difficulty may be met later in its removal by solvents. For accurate results complete freedom from all hydrocarbons must be assured. The lack of appreciation of the extreme difficulty experienced in removing every trace of grease from cast-iron and pig-iron gas samples can result in substantial percentages of methane and unsaturated hydrocarbons being found in the final gas analysis. All specimens of pig iron for vacuum-fusion gas analysis were cleansed carefully by at least three successive washings in pure ether.

The Degree of Accuracy of Vacuum-Fusion Gas Analysis

The accuracy attainable in vacuum-fusion analysis on cast irons and pig irons is being considered by a joint working committee of the British Cast Iron Research Association and the Institute of British

Table I

GAS CONTENT OF PIG IRON

No. (1)	Pig Iron (2)	Total Gas Content, ml./100 g. at N.T.P. (3)	Normal Method of Expressing Gas Content			Parts per Million		
			Hydrogen, ml./100 (4)	Oxygen, % (5)	Nitrogen, % (6)	Hydrogen, % × 10⁻⁴ (7)	Oxygen, % × 10⁻⁴ (8)	Nitrogen, % × 10⁻⁴ (9)
1	West-Coast Hematite... ...	16·6	8·0	0·005	0·002	7·0	50	20
2	,, ,, ...	47·1	16·7	0·020	0·003	15·0	200	30
3	,, ,, ...	129·0	14·4	0·081	0·002	13·0	810	20
4	,, ,, ...	47·3	17·7	0·020	0·002	15·5	200	20
5	East-Coast Hematite	12·3	5·9	0·004	0·001	5·5	40	10
6	,, ,, ...	14·5	5·9	0·003	0·005	5·5	30	50
7	Welsh Hematite	16·1	6·0	0·005	0·004	5·5	50	40
8	Cold-Blast Irons	10·2	3·0	0·003	0·004	2·5	30	40
9	,, ,, ...	9·8	2·9	0·004	0·002	2·5	40	20
10	,, ,, ...	8·3	2·4	0·002	0·004	2·0	20	40
11	,, ,, ...	13·6	6·3	0·004	0·002	5·5	40	20
12	,, ,, ...	17·9	5·8	0·007	0·003	5·0	70	30
13	Scottish Iron	21·3	4·7	0·009	0·005	4·0	90	50
	Northamptonshire Iron:							
14	High-Si close-grain ...	8·5	3·3	0·002	0·003	3·0	20	30
15	High-Si open-grain... ...	62·6	12·0	0·035	0·002	11·0	350	20
16	Low-Si close-grain	10·5	3·9	0·003	0·003	3·5	30	30
17	Low-Si open-grain	6·6	2·8	0·001	0·003	2·5	10	30
	Derbyshire Irons, 1920:							
18	No. 1	13·3	3·9	0·005	0·003	3·5	50	30
19	No. 2	27·4	7·4	0·012	0·004	6·5	120	40
20	No. 3	11·2	4·8	0·004	0·001	4·5	40	10
21	Foundry 4	11·3	3·1	0·003	0·005	3·0	30	50
22	Grey forge	17·1	6·2	0·006	0·003	5·5	60	30
23	Forge 4	29·5	3·9	0·016	0·004	3·5	160	40
24	Silky	11·3	4·1	0·004	0·002	3·5	40	20
	Derbyshire Irons, 1945:							
25	No. 1	10·2	1·5	0·005	0·002	1·5	50	20
26	No. 2	7·0	1·9	0·002	0·004	2·0	20	40
27	No. 3	15·9	3·7	0·007	0·003	3·0	70	30
28	Foundry No. 4	9·8	1·8	0·004	0·003	1·5	40	30
29	Grey forge	9·8	2·4	0·003	0·004	2·0	30	40
30	Forge 4	13·5	4·7	0·004	0·004	4·0	40	40
31	Silky	7·7	2·5	0·002	0·003	2·0	20	30

Foundrymen. From check determinations made during the course of the present investigatory work on British pig irons it is the authors' opinion that the values reported are within the following limits of accuracy :

	Average Contents, %	Degree of Accuracy
(1) Oxygen	0·001 –0·025	±0·001 of content
(2) Hydrogen	0·0001–0·0020	±0·0001 of content
(3) Nitrogen	0·001 –0·010	±0·001 of content

The accuracy of the vacuum-fusion analysis is certainly greater than the limits indicated above, but the difficulty of sampling pig iron, its openness of grain, and structural heterogeneity, must affect the duplication of results adversely. The following triplicate analyses were obtained during tests on specimens taken from the middle and near either end of the same piece of pig iron :

	Hydrogen, ml./100 g.	Oxygen, %	Nitrogen, %
(1)	7·9	0·080	0·004
(2)	6·2	0·075	0·003
(3)	7·2	0·079	0·003

The degree of error in these results was of the same order as was revealed when analyses were conducted on specimens from adjoining pieces of pig iron. It is thus unlikely that the scatter of results shown indicates any appreciable segregation of gas in the pig iron tested. Much more work would be required

to throw light upon the general question of gas segregation in iron. Vacuum-fusion analysis on specimens cut from ½-in. dia. chill-cast iron showed a considerably better degree of duplication than those on pig-iron specimens :

	Hydrogen, ml./100 g.	Oxygen, %	Nitrogen, %
(1*a*)	2·32	0·0010	0·0036
(1*b*)	2·35	0·0011	0·0036
(2*a*)	1·68	0·0016	0·0043
(2*b*)	1·56	0·0022	0·0039
(3*a*)	2·45	0·0016	0·0036
(3*b*)	2·70	0·0015	0·0043
(3*c*)	2·10	0·0011	0·0038
(4*a*)	2·00	0·0040	0·0043
(4*b*)	2·13	0·0037	0·0040

Since the work reported involved the determination of the gas content of samples cut, not from chill-cast test-bars, but from pig iron, the limits of accuracy in the determinations are probably of the order indicated on p. 132. For the majority of the pig-iron samples tested, duplicate and occasionally triplicate estimations were made and the results agreed to within these limits of error. The results shown in Table I are mean values of the several estimations in each case.

The Reporting of Gas Analyses

The usual method of reporting oxygen and nitrogen values as extracted from fused metals is to give them as percentages, involving, of necessity, a number of "noughts." Hydrogen is sometimes reported as a percentage and at other times as millilitres per 100 g. of sample. The latter method of expressing hydrogen certainly avoids ambiguity which otherwise might occur with very small amounts of the order of one ten-thousandth to one-thousandth of 1%, but it suffers from the defect that it tends to overrate the true amount of hydrogen present in relation to the other gases.

The authors have given some attention to the question of the best way of reporting gas-analysis figures, and whilst the ideal method cannot be claimed to have been found, it is felt that there is some merit in expressing the results as weight percentages in whole numbers multiplied by 10^{-4}. The concentration of the gases in the iron may then be conveniently stated as so many *parts per million*, which is a common method of measuring trace elements in chemistry. Thus 2 ml./100 g. of hydrogen at N.T.P. is equivalent to 0·00018% (density of hydrogen = 0·0899 g./litre) or a concentration in the iron of 1·8 parts per million. When the limits of accuracy of the gas estimation are taken into account this may be expressed in round figures as 2 parts per million. The gas concentrations are expressed in Table I in this form, but the more usual system of expression has also been included.

The total gas-content values reported in Table I were the actual experimental volumes found expressed as millilitres per 100 g. It is to be understood that this gas volume was made up of nitrogen and hydrogen from the iron sample and carbon monoxide which may have been derived from the interaction of oxygen-bearing compounds in the iron sample with the carbon of the crucible. It may be, of course, that some of the carbon monoxide was evolved as such from the sample during fusion ; indeed in some vacuum-heating experiments which have been made at 600° C. up to about one-third of the total gas evolved from solid specimens was carbon monoxide, the remainder being hydrogen. In support of this point of view it must be recognized that there is little microscopical evidence to suggest that appreciable amounts of oxide or silicate inclusions do exist in cast iron.[3] The authors have, therefore, considered it proper at this stage to report total gas-content values found experimentally without attempting to justify the carbon monoxide in terms of original oxygen content of the iron.

SPECTROGRAPHIC METHOD OF ANALYSIS

The spectrographic analysis of cast iron has been described by the authors in a previous paper to this Institute.[4] The pig irons were treated in a similar manner to that adopted in the authors' laboratory for routine iron samples. The normal spark technique was adopted for the estimation of nickel, chromium, copper, vanadium, and titanium ; for all other trace elements the semi-quantitative D.C. arc method was employed.

The generally coarse structure and somewhat heterogeneous nature of pig iron made it necessary in the interests of accuracy to average the results of three separate estimations. In this way the spectrographic results on pig irons were made to conform approximately to the same standard of accuracy as spectrographic determinations on chilled cast-iron specimens, which latter compare very favourably with chemical results for the trace elements. The degree of duplication obtainable for the spectrographic results shown in Table II is approximately ±0·005% of the content.

CHEMICAL METHODS OF ANALYSIS

The major elements carbon, silicon, sulphur, phosphorus, and manganese were determined by chemical analysis. The Strohlein volumetric combustion carbon apparatus was used to obtain the total and graphitic carbons, and the combined-carbon value was found by difference. Phosphorus, silicon, and manganese were determined by the well-known chemical procedures. The remaining element sulphur was analysed by the high-temperature oxygen-combustion method.

RESULTS

The results obtained from the various specimens examined are set out in Tables I and II. For obvious reasons brand names have been omitted, and the various pig irons are described by quality and district, and listed in numerical order. The hematite iron specimens, Nos. 1, 2, 3, 4, and 7, were machine-cast, and all the remaining specimens were sand-cast. They have been tabulated in the following order : Hematite, cold-blast, Scotch, Northamptonshire, and Derbyshire foundry qualities. In considering the results it is important to emphasize that there is as yet insufficient information available to justify them being regarded as typical values for the qualities and groups indicated by the description

Table II

GENERAL ANALYSIS OF AND ANALYSIS OF RESIDUALS IN PIG IRONS

No.	Chemical Analysis, %							Spectrographic Analysis, %									
	Total Carbon	Graphitic Carbon	Combined Carbon	Silicon	Sulphur	Manganese	Phosphorus	Nickel	Chromium	Copper	Molybdenum	Vanadium	Titanium	Aluminium	Boron	Arsenic	Tin
West-Coast Hematite:																	
1	3·07	2·76	0·31	5·59	0·016	0·55	0·030	0·02	0·01	0·03	0·010	0·010	0·06	0·020	Trace	0·045	Nil
2	4·04	3·35	0·69	1·32	0·023	1·29	0·027	0·02	0·01	0·02	0·010	0·010	0·02	0·020	Nil	0·010	Nil
3	4·15	3·40	0·75	2·30	0·028	0·69	0·033	0·02	0·02	0·03	0·020	0·010	0·03	0·030	Nil	0·020	Nil
4	3·40	3·30	0·10	5·05	0·022	0·66	0·051	0·02	0·02	0·03	0·010	0·010	0·07	0·060	Trace	0·045	Nil
East-Coast Hematite:																	
5	4·08	3·68	0·40	2·61	0·008	0·69	0·048	0·02	0·02	0·14	0·005	0·010	0·06	0·010	Nil	0·030	Nil
6	4·14	3·28	0·86	2·16	0·012	0·82	0·036	0·02	0·03	0·08	0·005	0·010	0·07	0·020	Nil	0·025	Nil
Welsh Hematite:																	
7	4·03	3·32	0·71	2·07	0·050	0·87	0·075	0·02	0·05	0·13	0·010	0·010	0·02	0·010	Nil	0·025	Nil
Cold-Blast Iron:																	
8	3·52	3·18	0·34	1·69	0·066	0·96	0·35	0·02	<0·01	<0·01	0·010	0·050	0·03	0·010	Nil	0·040	Nil
9	3·88	3·01	0·87	0·99	0·046	0·40	0·38	0·05	0·06	0·09	0·005	0·070	0·01	0·005	Nil	0·030	<0·01
10	3·50	2·71	0·79	0·96	0·098	0·73	0·28	0·13	0·07	0·16	0·010	0·090	0·02	0·010	Nil	0·030	<0·01
11	3·32	2·40	0·92	2·02	0·062	1·16	0·11	0·29	0·11	0·68	0·030	0·020	0·03	0·005	Nil	0·020	0·02
12	3·13	...	...	2·18	0·061	1·27	0·31	0·05	0·04	0·12	<0·005	0·090	0·01	0·020	Nil	0·020	0·08
Scottish Iron:																	
13	3·52	2·99	0·53	2·35	0·040	0·61	0·61	0·02	0·08	0·14	0·010	0·070	0·06	0·010	Nil	0·015	0·01
Northamptonshire Iron:																	
14	3·38	3·37	0·01	3·64	0·032	0·40	1·64	0·03	0·10	0·13	0·010	0·150	0·10	0·030	Nil	0·025	Nil
15	3·11	3·11	Nil	3·53	0·052	0·35	1·47	0·04	0·08	0·12	0·005	0·140	0·12	0·050	Nil	0·030	Nil
16	3·42	3·09	0·33	2·68	0·062	0·46	1·53	0·03	0·09	0·13	0·005	0·130	0·06	0·010	Trace	0·015	Nil
17	3·54	3·12	0·42	2·21	0·060	0·39	1·52	0·03	0·09	0·16	0·005	0·140	0·06	0·010	Trace	0·020	Nil
Derbyshire Irons, 1920:																	
18	3·72	3·38	0·34	2·63	0·020	0·79	1·26	0·08	0·08	0·03	0·010	0·180	0·10	0·015	Nil	0·025	Nil
19	3·59	3·28	0·31	2·56	0·030	0·80	1·36	0·07	0·08	0·03	0·010	0·170	0·09	0·010	Nil	0·040	Nil
20	3·69	3·44	0·25	3·09	0·014	0·73	1·56	0·07	0·08	0·02	0·010	0·200	0·11	0·030	Nil	0·045	Nil
21	3·37	3·05	0·32	2·10	0·058	0·93	1·46	0·06	0·08	0·02	0·010	0·160	0·07	0·020	Nil	0·030	Nil
22	3·28	2·80	0·48	2·71	0·084	1·11	1·38	0·07	0·08	0·02	0·010	0·180	0·10	0·040	Nil	0·035	Nil
23	3·25	2·71	0·54	1·82	0·041	0·71	1·27	0·06	0·09	0·02	0·010	0·160	0·06	0·010	Nil	0·030	Nil
24	2·90	2·90	Nil	4·47	0·057	0·80	1·30	0·10	0·10	0·02	0·010	0·140	0·10	0·030	Nil	0·045	Nil
Derbyshire Irons, 1945:																	
25	3·80	3·60	0·20	2·98	0·037	1·11	1·41	0·11	0·13	0·08	0·020	0·200	0·07	0·010	Nil	0·050	Nil
26	3·65	3·20	0·45	2·70	0·043	0·84	1·31	0·10	0·14	0·09	0·025	0·195	0·06	0·010	Nil	0·050	Nil
27	3·63	2·94	0·69	2·80	0·044	0·95	1·18	0·10	0·14	0·07	0·020	0·170	0·10	0·010	Nil	0·020	Nil
28	3·27	2·86	0·41	3·00	0·064	0·94	1·31	0·12	0·14	0·04	0·025	0·170	0·07	0·010	Nil	0·050	Nil
29	3·80	2·92	0·88	1·55	0·029	1·37	1·38	0·12	0·15	0·08	0·020	0·175	0·05	0·010	Nil	0·040	Nil
30	3·16	2·78	0·38	2·94	0·040	0·44	1·26	0·11	0·13	0·08	0·020	0·185	0·08	0·010	Nil	0·045	Nil
31	2·92	2·87	0·05	4·90	0·032	1·05	1·41	0·07	0·10	0·07	0·010	0·220	0·11	0·015	Nil	0·050	Nil

Total Gas Evolved

The total quantity of gases extracted per 100 g. of sample shows that certain types of hematite iron were not alone in yielding the largest volume percentages of extracted gases. Two of the 25-year-old phosphoric foundry irons of No. 2 and foundry forge fractures must be included in the list of specimens yielding over 20 ml. of gas per 100 g. and also one Northamptonshire pig iron.

Hydrogen

Quite substantial variations in hydrogen contents in the different specimens examined are revealed by the results in column 4 of Table I. The west-coast hematite specimens, Nos. 1, 2, 3, and 4, show hydrogen contents very much higher than any of the other results in this Table, except specimen No. 15, an open-grained Northamptonshire iron. The east-coast and Welsh hematites gave lower values and were very uniform in respect of hydrogen. The cold-blast irons, specimens Nos. 8 to 12, with the exceptions of 11 and 12, gave uniformly low hydrogen figures. It is quite likely that specimens 11 and 12, although described as cold-blast irons were produced under conditions different from the other three brands. The phosphoric irons, both Northamptonshire and Derbyshire qualities with the three exceptions noted, gave uniformly low values. The lowest values recorded are the No. 1, 2, and foundry 4 fractures of the recently manufactured Derbyshire iron. With the exception of the forge 4—1945 specimen, the hydrogen contents of the 1945 specimens were substantially lower than the 1920 irons. In view of the high silicon content of the forge 4—1945 specimen it is probable that this specimen can be regarded as abnormal. There does not appear to be any obvious relationship between the hydrogen contents and the fracture or microstructure.

Oxygen

The hematite specimens Nos. 2, 3, and 4, the specimen of Scotch iron No. 13, one Northamptonshire iron, and three of the Derbyshire iron specimens Nos. 19, 23, and 27, gave high figures of oxygen content, from 0·007% in No. 27 to 0·081% in No. 3. The oxygen figures for all the other irons were uniformly low, from 0·001 to 0·006%. In this connection it is of interest to refer to the results recorded on p. 132. These are the determinations of the hydrogen, oxygen, and nitrogen contents on three samples, cut from different portions of a specimen of the same brand and type of hematite iron as specimen No. 3. This particular specimen was taken at random from the stock pile lying in the authors' works and was not obtained specially from the makers. Whilst the hydrogen and nitrogen values differ from those recorded for this brand of iron in Table I there is a close similarity in the somewhat high oxygen value.

Nitrogen

Variations in nitrogen content are revealed by the results recorded in column 6 of Table I. The series of phosphoric Northamptonshire irons from the same furnace show a remarkable degree of uniformity, but this is not duplicated in the two series of Derbyshire irons, nor in the two hematite specimens Nos. 5 and 6, which are from the same furnaces. The nitrogen contents shown on p. 132 recorded for a further sample of the same brand of iron as specimen No. 3, Table II, show substantially higher values. The highest value recorded in this range of specimens examined was 0·005 in specimens Nos. 6 and 21, and the lowest 0·001% in specimens Nos. 5 and 20. Taking these into consideration the nitrogen values of these irons can be regarded as lying between approximately 0·001 and 0·006%.

Other Trace or Residual Elements

The other trace or residual elements determined spectrographically, were nickel, chromium, copper, molybdenum, vanadium, titanium, aluminium, arsenic, tin, and boron. With the exception of boron and tin, significant amounts of all these elements were found in all the specimens examined. (Table II.)

Nickel

The lowest nickel contents were found in all the hematite irons irrespective of brand or type, and one of the cold-blast irons No. 8, where in each case a value of 0·02% was recorded. The maximum nickel contents were found in two of the cold-blast irons, Nos. 10 and 11, in one of which—No. 11—a value of 0·29% was recorded. In the Derbyshire irons of the 1945 series the nickel content was noticeably higher than in the same series of irons of 25 years ago, and the Northamptonshire irons showed a uniform value of 0·03%, only slightly higher than the value recorded for the hematites.

Chromium

In the case of the element chromium, almost the same comments apply as for nickel. The lowest value recorded for this element was less than 0·01% in the cold-blast specimen No. 8. The values for the hematite irons ranged from 0·01 to 0·05%, and for the phosphoric-iron specimens from 0·06 to 0·15%.

Copper

The copper content of the cold-blast iron No. 11 at 0·68% is an exceptionally high figure. The significant amounts of copper, from 0·13% to 0·16%, in two of the hematite specimens Nos. 5 and 7, the cold-blast specimen No. 10, and the Scotch and Northamptonshire irons, will be noted. It is also of interest to observe an increased amount of this element in the 1945 as compared with the 1920 series of Derbyshire irons.

Molybdenum

It is very interesting to observe the presence of molybdenum in all the irons and, whilst the amounts are small, the figures show a definite increase in the 1945 as compared with the 25-year-old Derbyshire irons. The highest figure recorded was 0·03% in the cold-blast specimen No. 11.

Vanadium

All the hematite specimens show a uniform vanadium content at the low value of 0·01%. The cold-blast and Scotch irons showed a higher value from 0·02 to 0·09%. Quite significant amounts, up to as

much as 0·22% (specimen 31), were present in both the phosphoric Derbyshire and Northamptonshire irons.

Titanium

Derbyshire and Northamptonshire phosphoric irons were higher in titanium than any of the other irons tested. This element showed no important differences in the 1920 compared with the 1945 Derbyshire irons. The values for the remaining specimens of hematite, Scotch, and cold-blast irons range from 0·01% in specimen No. 12 to 0·07% in specimens Nos. 4 and 6.

Aluminium

There are some quite distinct variations recorded in the aluminium contents of the various specimens. The 25-year-old Derbyshire-iron specimens recorded a variable value of 0·01 to 0·04%, quite definitely higher than the 1945 specimens showing uniformly low values of 0·01%.

Boron

The element boron was sought for in a proportion of the specimens only, and in certain cases definite traces of the element were recorded.

Arsenic

Small amounts of arsenic were found in all the irons. The highest values occurred with the Derbyshire irons where the range was 0·020–0·050%. The lowest arsenic content was found in sample No. 2, a west-coast hematite. Not all the hematites were so low in arsenic, however, and another sample from the same manufacture (No. 1, Table II) gave 0·045%. The Northamptonshire and the cold-blast irons gave intermediate values in the range 0·015–0·045%.

Total Residuals

Apart from the exceptional case of specimen No. 11, where the total residual elements are 1·165%, in all cases the total amounts to quite significant percentages. In the phosphoric foundry irons the total of these elements averages at least 0·50%, and even in the hematite specimens the total may exceed 0·25%, amounts which cannot be neglected in the detailed examination of their behaviour in service. From the results as recorded, however, there is no obvious connection between any of these residual elements, either singly or in total on the fracture or microstructure of the pig iron.

A CRITICAL CONSIDERATION OF RESULTS OF GAS DETERMINATION

The data presented are considered by the authors to be too incomplete to enable any conclusions except of a general nature to be drawn as a result of this preliminary survey. The whole subject of the gas determinations of pig iron is in its infancy and although a fairly comprehensive examination of British foundry pig irons has been made it must be remembered that in general only one sample of each has been examined. Where more than one piece of pig was analysed substantial differences were reported which, although not of sufficient magnitude to outweigh the general conclusions, may yet appear large when viewed from the standpoint of ordinary chemical analysis of the same pig irons.

Despite this, a few observations are perhaps not untimely.

Oxygen and Hydrogen Contents

It was noted that there was a tendency to find that in pig irons with high oxygen content the hydrogen also tended to be higher than the average. Whilst it was not possible to detect a regular variation with type of iron or even an established ratio of hydrogen to oxygen, the tendency for these gaseous impurities to progress in step cannot be overlooked. It is perhaps not to be expected that a fixed ratio of hydrogen to oxygen would be found as it is not known at this stage how much of the recorded oxygen is due to carbon monoxide evolved in the gaseous form from the metal and how much is due to the reduction of oxide inclusions present in the iron.

Nitrogen Content

In contrast to the two other gases the occurrence of nitrogen is confined within fairly narrow limits ranging from 0·001% to 0·006%. This fact is of some little interest when it is considered that quite large variations in nitrogen content have been recorded with steels, *i.e.*, 0·002 in a boiler-plate steel to 0·019 in a rimming basic Bessemer steel.[5]

Total Volume of Gases

It is not known at this stage what is the metallurgical significance of variations of total gases in pig iron. It is, however, important to observe that in some instances quite large amounts of gases have been found. The largest evolution of gas was found with a Northamptonshire iron which gave a gas volume expressed at N.T.P. of over one-half the volume of the solid specimen.

Acknowledgment

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Inter-Relation of Hardenability and Isothermal Transformation Data

By W. I. Pumphrey, M.Sc., and F. W. Jones, Ph.D.

SYNOPSIS

In view of the widespread use of the isothermal transformation method for studying the breakdown of austenite, the relation of such data to the hardenability of steel, which from the practical point of view is of major importance, has been considered.

It has been suggested by previous workers that during continuous cooling the fractional nucleation times (*i.e.*, the time spent at a given temperature divided by the induction period at that temperature) are additive in any one transformation range, and that transformation begins when the sum of such fractional nucleation times attains a value of unity. By an extension of this concept, continuous-cooling data have been calculated from the isothermal transformation diagram, and in particular the method has been used to calculate the hardness along a Jominy bar. For the three steels considered, a hypereutectoid chromium–molybdenum steel and two hypo-eutectoid nickel steels, the hardenability curves calculated in this way were found to be in reasonable agreement with those determined experimentally.

Introduction

THE mechanical properties of a steel depend to a large extent on its hardenability, which is therefore of considerable practical importance. From the experimental and theoretical aspects the decomposition of austenite is most conveniently studied isothermally, so that it is very desirable to be able to relate, quantitatively, the hardenability of a steel (which depends upon its transformation behaviour during continuous cooling) with its isothermal transformation diagram.

A number of investigators have endeavoured to derive a continuous-cooling diagram from isothermal transformation data. Bain,[1] in 1932, published a schematic cooling diagram for a eutectoid carbon steel, indicating the curve for the beginning of transformation and the structures produced by several typical cooling rates. Davenport[2] subsequently pointed out the need for correlating the transformation during continuous cooling, with isothermal data, and outlined the principle of a "continuous-cooling diagram." Neither of these workers, however, developed a practical method of correlating, quantitatively, the two types of transformation diagram. Scheil,[3] and later, Steinberg,[4] presented a method for calculating the temperature at which transformation begins during continuous cooling, which has provided a basis for most of the subsequent work on the subject. Scheil suggested that during cooling, the fractional nucleation times (*i.e.*, the time spent at a given temperature divided by the induction period at that temperature) are additive and that the transformation begins when the sum of such fractional nucleation times attains the value of unity. Grange and Kiefer[5] used a method for calculating the temperature at which transformation begins during cooling, which differs somewhat from that of Scheil's, but appears to have no advantages over it. As regards formal exactness, their method is less satisfactory, although it is unlikely that appreciable errors are introduced by their assumptions. Grange and Kiefer also considered the question of the progress of transformation after it had commenced at a certain temperature.

Manning and Lorig[6] subsequently extended the basic theory of Scheil and Steinberg by suggesting that fractional nucleation times in one transformation range are not additive to those in another; *i.e.*, that fractional nucleation in the bainite region is not additive to previous nucleation in the pearlite region because of the difference in the mode of nucleation in the two transformation ranges. Manning and Lorig applied this concept to the determination of the temperature at which transformation begins during cooling, but did not extend their work to a consideration of the progress of transformation after it had commenced.

The importance of the non-additive nature of the fractional nucleation periods in the different transformation ranges, and the necessity for a knowledge of the effect of partial austenite decomposition at one temperature upon subsequent decomposition at another (lower) temperature, were noted by Hollomon, Jaffe, and Norton,[7] who published a review summarizing present knowledge on these aspects of continuous-cooling transformation.

Where more than one type of transformation occurs in a steel, *e.g.*, pearlitic and intermediate, it is theoretically possible to calculate, from isothermal data, the progress of the transformation during continuous cooling, if the two types of transformation are either entirely additive or entirely independent. If, however, the rate of transformation at any temperature depends upon the amount of transformation which has taken place at some higher temperature, then the usual isothermal diagram is inadequate for the consideration of the transformation behaviour during continuous cooling. Although there is some evidence[8] that the transformations in a steel are in fact interdependent, the authors have attempted, in the present paper, to determine to what extent agreement between isothermal and continuous-cooling data can be obtained

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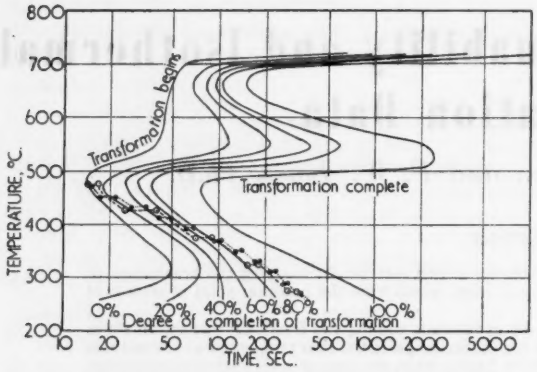

Fig. 1—Isothermal transformation curve for steel No. 1, for an austenitizing temperature of 815° C.

if the interdependence of the two types of transformation is ignored. Without such an assumption it appears impossible to derive any relationship between isothermal and continuous-cooling data, so that unless reasonable agreement can be obtained between the two sets of data by use of this assumption, then the **S** curve is of somewhat dubious utility where questions of hardenability are concerned.

Previous workers have not attempted to correlate the hardness along the Jominy bar, obtained experimentally, with that calculated from the **S** curve. In view of the practical importance of the Jominy test, and the fact that, from the experimental and theoretical aspects, the decomposition of austenite is most easily studied isothermally, it appeared worth while to attempt the correlation of hardness data obtained during transformation under isothermal and continuous-cooling conditions.

EXPERIMENTAL PROCEDURE

In an earlier investigation[9] a determination was made of the hardenability characteristics of a hypereutectoid chromium–molybdenum steel. In addition, a study was made, by the interrupted end-quench method, of the range of temperatures over which transformation occurs in this steel during continuous cooling from the austenitic condition. The steel, designated steel No. 1 in the previous investigation, had the following composition:

C, %	Si, %	Mn, %	Ni, %	Cr, %	Mo, %
0·74	0·25	0·34	0·21	1·43	0·23

Because of the information already possessed on the transformation characteristics of steel No. 1 during continuous cooling, it was felt that this steel would be most suitable for the preliminary examination of the relationship between isothermal transformation and transformation during continuous cooling.

The isothermal-transformation characteristics of steel No. 1, determined dilatometrically, are shown plotted in the form of an **S** curve in Fig. 1. Since in the earlier work an austenitizing temperature of 815° C. was employed, this temperature was used in the present experimental determination of the **S** curve to facilitate comparison between the isothermal and continuous-cooling data and, unless otherwise stated, the experimental data presented in this paper for steel No. 1 all refer to an austenitizing temperature of 815° C. with a time at temperature of 20 min. In Fig. 2 the hardnesses of the isothermally-transformed specimens are plotted against the temperature of isothermal transformation. Each specimen was water quenched from the lead bath after an appropriate period of immersion, and in Fig. 2 each hardness value is the average of at least three determinations made on a flat ground along the length of the dilatometer specimen.

Calculation of Continuous-Cooling Data from the S Curve

If, for any particular steel, the form of the **S** curve is known and if, in addition, the cooling curves at different positions along the length of a Jominy bar of the steel end-quenched from the same austenitizing temperature are known, then, by an application of the concept of Scheil, to which reference has been made, an estimation can be made of the temperature at which transformation will begin at any point along the length of the Jominy bar during continuous cooling from the austenitic condition.

Suppose that at a particular temperature T the cooling rate over the temperature interval δT is $\frac{\delta T}{\delta t}$, and that the induction period at this temperature is I_T. Then the steel spends a fraction $\frac{\delta t}{I_T}$ of its induction period in the temperature range δT. According to Scheil the transformation starts at some time t_1 when

$$\int_{t=0}^{t=t_1} \frac{\delta t}{I_T} = 1$$

The time zero is taken from the time the steel reaches the temperature at which the transformation will commence after a long period of time (say, of the order of a day).

The work of Manning and Lorig[6] showed that fractional nucleation times in the pearlite transformation range are not additive to those in the intermediate range, because of differences in the modes of nucleation of transformation in the two regions.

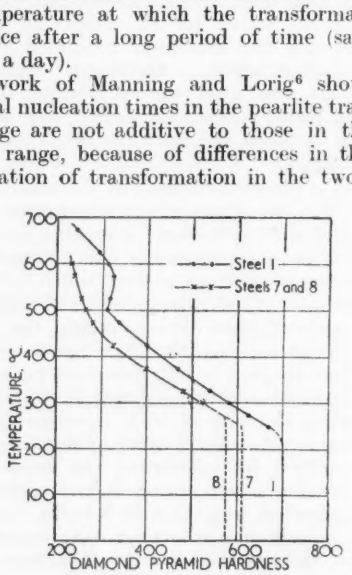

Fig. 2—Variation of hardness of isothermally transformed specimens with temperature of transformation

When both transformations occur in one steel, calculations must be made separately for the two transformations, choosing the appropriate time zero in each case. As will be noted, greater accuracy will be obtained in the calculation of the above equation the smaller the temperature interval considered.

In the case of steel No. 1 the pearlite transformation range extends down to approximately 550° C. (*see* Fig. 1); between 550° C. and 250° C. transformation to intermediate products occurs; and below 250° C. such transformations as occur are wholly martensitic. As mentioned above, fractional nucleation times in the pearlite transformation range are not additive with those in the intermediate range; thus, if the sum of the fractional nucleation times in the pearlite range is less than unity, transformation can only occur below 550° C. For this steel it has been assumed that nucleation times in the bainitic region are independent of the time the steel spends in the pearlitic region. If the sum of the fractional nucleation times in the pearlitic range is greater than or equal to 1, transformation may occur in both the pearlite and the intermediate ranges.

Consider, now, a point 0·75 in. from the end of a Jominy bar of steel No. 1 which is being end-quenched after 20 min. at 815° C., and suppose that cooling takes place in intervals of 50° C. Then, under these conditions, on the basis of the above mathematical relationship, the figures given in Table I are obtained.

The sum of the fractional nucleation times at temperatures greater than 550° C. is thus less than unity, and transformation cannot therefore commence in the pearlite range. To determine the temperature at which transformation commences in the intermediate range, the above calculation must be repeated for temperatures below 550° C. Proceeding in the same manner, the results shown in Table II are obtained for temperatures below 550° C.

Under the particular cooling conditions considered, transformation at 0·75 in. from the quenched end of the Jominy bar begins at 475° C. The progress of transformation at this point during further cooling may then be calculated as follows:

From the figures given in Table II, transformation begins after 9·5 sec. in the range 500–450° C. and proceeds for the remaining 2·6 sec. that the material spends in this temperature range. Under strictly isothermal conditions the transformation commences at 475° C. after 14·5 sec., thus, in effect, the amount of transformation that proceeds in 2·6 sec. is equivalent to that which would occur if the material was maintained for 17·1 sec. (14·5 sec. plus 2·6 sec.) at 475° C. After 17·1 sec. at 475° C. the steel is 15% transformed (*see* Fig. 1).

Consider, now, the temperature interval 450–400° C.; the time to cool through this range is 15·3 sec., and the mean temperature is 425° C. With the method of considering the transformation at 50° intervals it is assumed that the temperature of 425° C. is attained with 15% of the austenite transformed. At 425° C. the steel is 15% transformed after 25 sec.; after a further 15·3 sec., *i.e.*, after a total time of 40·3 sec., 51% of the austenite is transformed. Thus, 36% (51% − 15%) transforms at 425° C. In a similar manner it can be calculated that at 375° C. the transformation is 81% complete, at 325° C. it is 85% complete, and at 275° C. it is 87% complete. The 13% of austenite remaining untransformed at 275° C. transforms to martensite on further cooling below 250° C. The following results may be drawn from the above calculation:

Mean Temp., °C.	Degree of Completion of Transformation at Mean Temp., %	Portion of Austenite Transformed at Mean Temp., %
475	15	15
425	51	36
375	81	30
325	85	4
275	87	2
Below 250	100	13

From these results it is now required to calculate the hardness. The most reasonable assumption appears to be that the hardness of the final transformation product resulting from continuous cooling is given by the formula:

$$H = aH_1 + bH_2 + cH_3 + \ldots$$

where a, b, c, etc., are the proportions transformed in the various temperature zones, and H_1, H_2, H_3, etc., are the hardnesses of the isothermal transformation products at the mean temperature of the zone. No

Table I

Temp. Interval, °C.	Time of Cooling through Temp. Interval,* sec.	Mean Temp., °C.	Induction Period at Mean Temp., sec.	"Proportion Inducted" in Temp. Range	Total Inducted
750–700	5·3	725	90	0·06	0·06
700–650	5·9	675	50	0·12	0·18
650–600	6·7	625	46	0·15	0·33
600–550	7·8	575	43	0·18	0·51

* *See* Appendix which gives figures calculated from the results of Russell and Williamson.[10]

Table II

Temp. Interval, °C.	Time of Cooling through Temp. Interval, sec.	Mean Temp., °C.	Induction Period at Mean Temp., sec.	"Proportion Inducted" in Temp. Range	Total Inducted
550–500	9·5	525	27	0·35	0·35
500–450	12·1	475	14·5	0·65 in 9·5 sec.	1·0

Table III

Mean Temp., °C.	Proportion Transformed at Mean Temperature	Hardness of Transformation Product at Mean Temp., D.P.H	Contribution to Total Hardness at 0·75 in. from Quenched End, D.P.H.
475	0·15	340	51
425	0·36	400	144
375	0·30	463	139
325	0·04	540	22
275	0·02	627	13
Below 250	0·13	700	91
			460

Table IV

Mean Temp., °C.	Proportion Transformed at Mean Temperature	Hardness of Transformation Product at Mean Temp., D.P.H.	Contribution to Total Hardness at 0·75 in. from Quenched End, D.P.H.
470	0·05	343	17·1
450	0·20	367	74·0
430	0·15	393	59·0
410	0·18	417	75·0
390	0·17	443	75·0
370	0·08	470	38·0
350	0·01	498	5·0
330	0·01	540	5·4
310	0·01	566	5·7
290	0·005	600	3·0
270	0·005	640	3·2
250	0·01	670	6·7
Below 250	0·12	700	84·0
			451·1

consideration is given to the effect of continued holding at the transformation temperature on the hardness of the portion of the austenite already transformed, since it is considered that in general the effect of holding time on the hardness will be relatively small.

Using the data plotted in Fig. 2, the hardness to be expected at a point 0·75 in. from the end of a Jominy bar of steel No. 1 (end-quenched from 815° C.), calculated from the data shown in Table III, is 460 D.P.H. by summation of column 4.

To obtain some idea of the errors caused by taking 50° C. intervals, as in Table III, the calculation of the hardness to be expected at 0·75 in. from the quenched end of a Jominy bar of steel No. 1 was repeated for temperature intervals of 20° C., with the results given in Table IV. The calculated hardness was 451 D.P.H., which figure differs only by 9 points from the result obtained when using 50° C. intervals.

The calculation of continuous-cooling data from the isothermal diagram is somewhat laborious when based on temperature intervals of 20° C. and since there is little difference in the hardnesses at any one point along the length of the Jominy bar, as given by both methods of calculation, temperature intervals of 50° C. have been used as the basis for all the calculated results recorded in the present paper. For the convenience of other workers who may wish to use the suggested method for hardness calculation a number of Tables (*see* Appendix) has been compiled from the experimental data of Russell and Williamson.[10] These give the times taken to cool through intervals of 50° C. at different positions along the lengths of Jominy bars end-quenched from a number of different temperatures.

The difference in the calculated progress of the transformation at 0·75 in. from the end of the Jominy bar, with the two temperature intervals considered, is illustrated by the broken and dotted lines superimposed on the **S** curve in Fig. 1, which represent the progress of transformation calculated assuming temperature intervals of 50° C. and 20° C., respectively. With this method of calculation, transformation is considered as proceeding in a series of steps and, as will be seen, the steps in the curves indicating the progress of the transformation, using the temperature intervals of 50° C. and 20° C., are very similar.

At a point 1·5 in. from the quenched end of a Jominy bar of steel No. 1, calculation indicates that transformation begins in the pearlite range and is completed in the intermediate range. Proceeding as above, it can be calculated that, in the pearlite range, transformation begins at 625° C. and is 12% completed at 550° C., the lower limit of the pearlite range. For the calculation of the progress of transformation below 550° C. a summation of the fractional nucleation times must again be made to determine the temperature at which transformation of the remaining austenite (88%) commences in the intermediate range. In this range the calculated temperature for the beginning of transformation is 475° C., and at this temperature 81% of the austenite still untransformed is transformed to the intermediate product, *i.e.*, at 475° C. the proportion transformed is 0·81 × 0·88, 0·71. Continuation of the calculation to completion, and calculation of the hardness in the manner already detailed, indicates that, at the point under consideration, the hardness after end-quenching from 815° C. will be 349 D.P.H.

If it is assumed that transformation in the intermediate range is continuous with that in the pearlite range, and that there is no necessity for a discontinuous calculation of the progress of transformation, it can be estimated that the hardness at 1·5 in. from the quenched end of the Jominy bar, after end-quenching, will be 346 D.P.H. While the results given by the two methods of calculation are almost identical the former method of discontinuous calculation is to be

Table V

CALCULATION OF HARDNESS ASSUMING DISCONTINUOUS TRANSFORMATION

Mean Temp., °C.	Proportion Transformed at Mean Temperature	Hardness of Transformation Product at Mean Temp., D.P.H.	Contribution to Total Hardness at 1·5 in. from Quenched End, D.P.H.
625	0·04	294	12
575	0·08	325	26
525	...	...	...
475	0·71	340	241
425	0·13	400	52
375	0·04	463	18
			349

Table VI

CALCULATION OF HARDNESS ASSUMING CONTINUOUS TRANSFORMATION

Mean Temp., °C.	Proportion Transformed at Mean Temperature	Hardness of Transformation Product at Mean Temp., D.P.H.	Contribution to Total Hardness at 1·5 in. from Quenched End, D.P.H.
625	0·04	294	12
575	0·08	325	26
525	0·13	320	42
475	0·58	340	198
425	0·17	400	68
			346

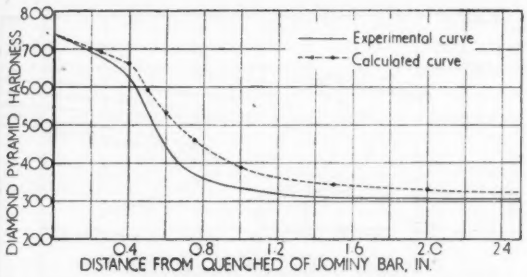

Fig. 3—Experimental and calculated hardenability curves for steel No. 1, end-quenched from 815° C.

preferred as being theoretically the more correct. The results given by the two methods of calculation are contrasted in Tables V and VI. Although the final hardness results are almost identical it will be noted that the progress of the transformation calculated assuming discontinuous transformation, is very different from that calculated on the basis of the less correct assumption of continuous transformation.

The hardnesses to be expected at a number of points along the length of a Jominy bar of steel No. 1 end-quenched from 815° C. were estimated using the method of calculation based on discontinuous transformation. The calculated hardenability curve is compared with that determined by experiment in Fig. 3. The two curves are in reasonable agreement.

Calculation of Form of Interrupted End-Quench Curves

In a previous investigation[9] the temperature range over which a steel transforms during continuous cooling was determined by means of the interrupted end-quench method. In this method the results are plotted in the form of curves which relate the hardness obtained at any point along the length of a Jominy bar, with the temperature at that point at the instant before the total quenching of the bar. The transformation range of the steel under consideration is then taken as that range of temperatures on the curves over which the hardness is changing rapidly. Similar hardness/temperature curves may be calculated by means of the method under discussion.

The transformation ranges of the steels considered may also be obtained from the calculations already made in the present paper. Figure 4 permits a comparison of the transformation ranges obtained from the **S** curve and from interrupted-quench data for steel No. 1. From the **S**-curve data the percentage transforming in each 50° C. temperature interval was plotted against the mean temperature. From Fig. 27 of the paper by Pumphrey and Jones[9] the hardness

Table VII

Distance from Quenched End of Jominy Bar, in.	Temperature of Maximum Transformation, C.	
	From S Curve	From Interrupted Quench Curves
0·4	Indeterminate, <350	Indeterminate, <350
0·6	380	390
0·75	410	445
1·0	455	475

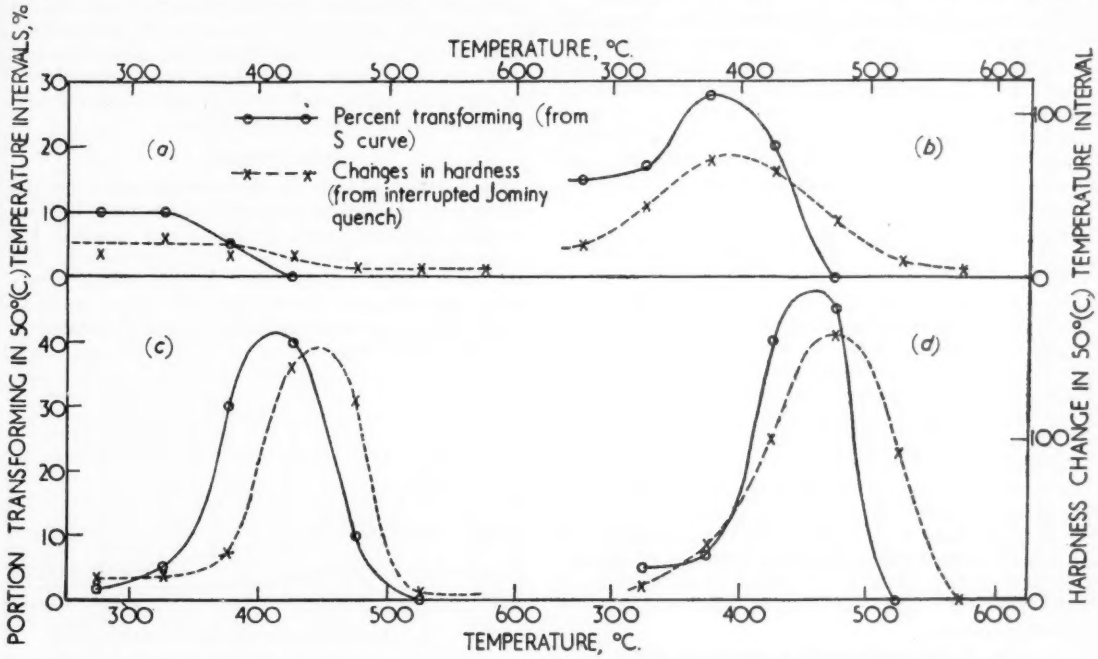

Fig. 4—Comparison of transformation ranges obtained from S-curve and interrupted-quench data for steel No. 1 (*a*) 0·4 in., (*b*) 0·6 in., (*c*) 0·75 in., and (*d*) 1·0 in., from quenched end of Jominy bar

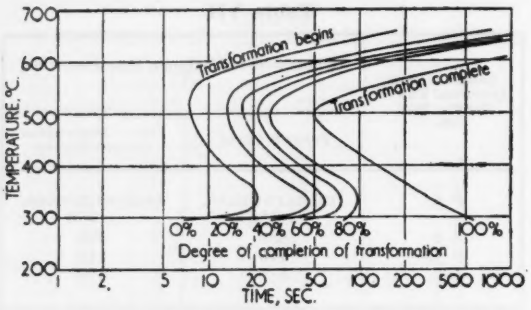

Fig. 5—Isothermal transformation curve for steel No. 7, for an austenitizing temperature of 880° C.

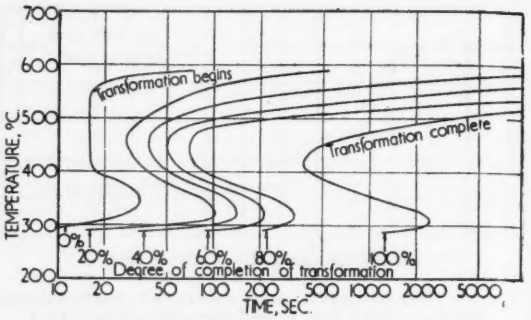

Fig. 6—Isothermal transformation curve for steel No. 8, for an austenitizing temperature of 880° C.

change for each 50° C. temperature interval was obtained and plotted against the mean temperature. As has already been stated, on curves such as those in Fig. 27 of that paper, transformation is shown by change of hardness on the curve, and to a first approximation the amount of transformation occurring over a certain temperature interval can be regarded as proportional to the rate of change of hardness. The curves from the two different sources show a fair correspondence. The temperatures at which maximum transformation occurs, read off from the curves in Fig. 4 of this paper, are given in Table VII.

There appears to be a systematic difference, of the order of 20° C., between the two sets of results, but in view of the simplifications involved in the calculations the agreement can be considered as reasonably satisfactory.

Application of the Method to Other Steels

The method under consideration having proved of value for the calculation of continuous-cooling data from the isothermal transformation diagram in the case of a hypereutectoid chromium–molybdenum steel, it was thought it would be of interest to extend the method to the calculation of continuous-cooling data for two hypo-eutectoid steels of different compositions. The two steels examined had the following analyses:

Steel No.	C, %	Si, %	Mn, %	Ni, %	Cr, %	Mo, %
7	0·39	0·20	0·86	1·12	0·13	0·05
8	0·28	0·25	0·62	3·78	0·15	—

For the experimental determination of the **S** curves and hardenability curves of the two steels an austenitizing temperature of 880° C. was used. The **S** curves determined dilatometrically for the two steels under this austenitizing condition are shown in Figs. 5 and 6. The curves relating the hardnesses of the isothermally transformed specimens of steels No. 7 and No. 8 with the temperatures of isothermal transformation, were found to be identical for the two steels. The curve applying to both steels is shown plotted in Fig. 2.

It might here be noted that in the calculations it has been assumed that the mean hardness of martensite formed below 300° C. is 610 D.P.H. for steel No. 7, and 575 D.P.H. for steel No. 8, which has a lower carbon content.

In Fig. 7, the hardenability curves of steels No. 7 and No. 8, calculated in a similar manner to that used for steel No. 1, are shown compared with the same curves determined by experiment. In the calculations it was assumed that one type of transformation only was obtained with these steels, *i.e.*, no differentiation has been made between pearlite and intermediate transformations. In view of the shape of the **S** curves and the small difference between the results obtained assuming "discontinuous" and "continuous" transformation with steel No. 1, this procedure appears justifiable. There is, again, fair agreement between the calculated and experimental results, and, in particular, the method of calculation has served to differentiate clearly between the hardenability levels of the two steels.

Considering the curves shown in Fig. 7 and in Fig. 3, it can be seen that over the steeply sloping portion of the Jominy curve the maximum difference between calculated and experimental figures is 90 points D.P.H. In the case of the hypereutectoid steel (steel No. 1) the calculated hardness is higher than that determined by experiment, whilst in the case of the hypo-eutectoid steels (steels No. 7 and No. 8) it is, in general, lower. At points away from the steeply sloping portion of the curve the agreement between the calculated and experimental figures is much better.

DISCUSSION

The method adopted in the present paper, for the calculation of continuous-cooling data from the isothermal transformation diagram, has enabled the hardness along a Jominy bar to be calculated. For the three steels considered, a hypereutectoid chromium–molybdenum steel and two hypo-eutectoid nickel steels, the hardenability curves calculated in this way were found to be in reasonable agreement

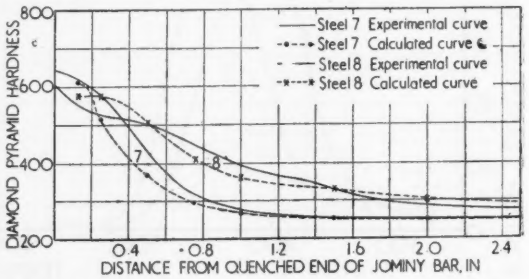
Steel 7 Experimental curve
Steel 7 Calculated curve
Steel 8 Experimental curve
Steel 8 Calculated curve
DIAMOND PYRAMID HARDNESS
DISTANCE FROM QUENCHED END OF JOMINY BAR, IN

Fig. 7—Experimental and calculated hardenability curves for steels No. 7 and No. 8, end-quenched from 880° C.

with those determined experimentally. Although calculations and experiments have not been carried out with all possible steel compositions, the present paper indicates the validity of the method for steels of the types considered, and suggests that the hardenability of a steel may be related quantitatively with its **S** curve. A further point of great practical importance is the question of the range of temperatures over which transformation occurs in a steel during continuous cooling, since the mechanical properties are considerably affected by the temperature at which a steel transforms. The methods used by the authors enable the transformation range during continuous cooling to be obtained from the **S** curve. For the hypereutectoid chromium–molybdenum steel the range calculated in this way shows fair agreement with that obtained by the method of the interrupted Jominy quench.

Table A

TIME TO COOL THROUGH 50° C. AT DIFFERENT POSITIONS ALONG THE LENGTHS OF JOMINY BARS END-QUENCHED FROM 800° C.

Temp. Interval, °C.	Time to Cool Through Temperature Interval, sec.						
	0·125 in.	0·25 in.	0·5 in.	0·75 in.	1·0 in.	1·5 in.	2·0 in.
750–700	0·2$_6$	0·6	2·5	5·2	7·8	12·7	19·0
700–650	0·2$_9$	0·7$_5$	2·8$_5$	5·8	8·7	14·0	21·5
650–600	0·3$_5$	0·9$_6$	3·4	6·5$_5$	9·9	15·6	24·3
600–550	0·4$_1$	1·2$_5$	4·1$_5$	7·6	11·5	17·9	27·9
550–500	0·5$_1$	1·6	5·2	9·4	13·7	21·0	32·5
500–450	0·6$_6$	2·3	6·5	11·8	16·5	25·0	39
450–400	0·9$_1$	3·1$_5$	8·4	15	20·8	31·5	49
400–350	1·4	4·5	11	20	27·1	42	63
350–300	2·3$_5$	6·6	15	28	36	58	84
300–250	4·8	10·7	23	42	57	84	112
250–200	10·6	17·5	47	71	115	128	150

Table B

TIME TO COOL THROUGH 50° C. AT DIFFERENT POSITIONS ALONG THE LENGTHS OF JOMINY BARS END-QUENCHED FROM 825° C.

Temp. Interval, °C.	Time to Cool Through Temperature Interval, sec.						
	0·125 in.	0·25 in.	0·5 in.	0·75 in.	1·0 in.	1·5 in.	2·0 in.
750–700	0·2$_6$	0·6$_7$	2·5	5·4	7·8	14·0	21·0
700–650	0·3$_1$	0·8$_1$	2·9	6·0	8·8	15·3	22·8
650–600	0·3$_7$	1·0	3·4	6·8	9·9	16·5	25·2
600–550	0·4$_4$	1·3	4·1$_5$	7·9	11·5	18·8	28·6
550–500	0·5$_5$	1·7$_4$	5·2$_5$	9·6	14·0	22	33·8
500–450	0·7$_2$	2·4	6·7	12·3	17·0	27	41
450–400	1·0	3·4	8·6	15·5	21·5	34	53
400–350	1·5$_5$	4·7	11·2	20	28	47	69
350–300	2·6	6·9	16	29	39	63	90
300–250	5·2	10·8	25	43	64	88	123
250–200	11·4	17·5	48	75	119	134	170

Table C

TIME TO COOL THROUGH 50° C. AT DIFFERENT POSITIONS ALONG THE LENGTHS OF JOMINY BARS END-QUENCHED FROM 850° C.

Temp. Interval, °C.	Time to Cool Through Temperature Interval, sec.						
	0·125 in.	0·25 in.	0·5 in.	0·75 in.	1·0 in.	1·5 in.	2·0 in.
750–700	0·3	0·7$_4$	2·5$_5$	5·4	8·5	14·0	22·0
700–650	0·3$_4$	0·8$_9$	3·0	6·1	9·4	15·3	23·5
650–600	0·4	1·1$_1$	3·6$_2$	7·0	10·4	17·0	26·0
600–550	0·4$_7$	1·4$_5$	4·4$_5$	8·3$_5$	11·9	19·2	29·6
550–500	0·5$_8$	1·9$_3$	5·5$_5$	10·1	14·0	22·8	35·0
500–450	0·7$_5$	2·6	7·0	12·8	17·0	27·5	43·5
450–400	1·0	3·6	9·0	16	21·8	35·8	56
400–350	1·6	5·0	12·0	21	29	47·5	74
350–300	2·8	7·2	16·2	29	41	65	98
300–250	5·8	11·5	25	44	68	94	132
250–200	12·2	18·5	52	85	132	150	179

Table D

TIME TO COOL THROUGH 50° C. AT DIFFERENT POSITIONS ALONG THE LENGTHS OF JOMINY BARS END-QUENCHED FROM 875° C.

Temp. Interval, °C.	Time to Cool Through Temperature Interval, sec.						
	0·125 in.	0·25 in.	0·5 in.	0·75 in.	1·0 in.	1·5 in.	2·0 in.
750–700	$0·3_1$	$0·7_4$	2·6	5·5	8·5	14·0	22·0
700–650	$0·3_5$	$0·9_2$	3·1	$6·1_5$	9·4	15·5	24·0
650–600	0·4	1·2	3·7	7·1	10·6	17·3	26·9
600–550	$0·4_7$	$1·5_3$	4·6	8·6	12·3	20·5	30·5
550–500	$0·5_9$	2·0	5·7	10·5	14·9	24·5	36·0
500–450	$0·7_8$	2·7	7·1	13·3	18	30	44·5
450–400	1·1	3·7	9	16·8	23	37	56
400–350	$1·8_6$	$5·1_5$	12	22·3	30	48	74
350–300	$3·1_5$	7·6	17	30	44	65	99
300–250	6·3	12·0	29	47	70	96	135
250–200	13	18·5	52	85	134	155	188

Table E

TIME TO COOL THROUGH 50° C. AT DIFFERENT POSITIONS ALONG THE LENGTHS OF JOMINY BARS END-QUENCHED FROM 900° C.

Temp. Interval, °C.	Time to Cool Through Temperature Interval, sec.						
	0·125 in.	0·25 in.	0·5 in.	0·75 in.	1·0 in.	1·5 in.	2·0 in.
750–700	$0·3_1$	$0·7_6$	$2·6_5$	5·5	8·7	14·2	22·5
700–650	$0·3_5$	$0·9_6$	$3·1_5$	6·2	9·8	15·8	24·5
650–600	0·4	$1·2_3$	3·8	7·2	11·1	18·0	27·5
600–550	$0·4_9$	$1·6_2$	4·7	8·7	12·9	21·0	31·5
550–500	$0·6_2$	$2·1_7$	5·8	10·7	15·1	25·0	38
500–450	$0·8_5$	$2·9_3$	7·2	13·6	18·7	30·5	47
450–400	$1·2_5$	$3·9_8$	9·4	17	24	38	59
400–350	$1·9_4$	5·5	12·6	23	32	49	76
350–300	3·4	8	18	32	47	67	99
300–250	6·7	12	30	48	75	99	136
250–200	14	19	60	94	139	164	198

Appendix

In Tables A to E are given the times taken to cool through intervals of 50° C. at different positions along the lengths of Jominy bars end-quenched from different temperatures. The results contained in the Tables have been extrapolated and interpolated from the experimental data of Russell and Williamson,[10] who determined the cooling curves at different positions along Jominy bars of steel EN 100 during end-quenching. While no high degree of absolute accuracy can be claimed for the results in Tables A to E, they are of sufficient generality to be used with confidence for the calculation of continuous-cooling data from the isothermal transformation diagram of any steel in the manner detailed in the body of the present paper.

Acknowledgments

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A Magnetic Study of Stainless-Steel Wires

By

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SYNOPSIS

After a brief reference to a method developed for the examination of very fine single wires for magnetic properties, the results of experiments on iron–nickel–chromium wires are described, and suggestions are put forward for the crystal structure of these two-phased cold-worked alloys.

Typical remanence (B_r–H) curves for such wires are analysed by a modification of the method developed by Richer, and reasonable values for preferred directions of crystal-orientation and domain-orientation are obtained. After a description of differential susceptibility curves, and a note of their importance in detecting minute irregularities of magnetization, possible factors governing the acquisition of irreversible magnetization at higher fields than that giving maximum susceptibility are discussed.

The observed changes in magnetic properties after different degrees of heat-treatment are next described, and the results of the analysis of B_r–H curves and the incidence of irregularities are discussed in the light of the conclusions of previous investigators upon the structural changes consequent upon such treatment. A general description follows of the type of irregularities observed in some wires which have not been heat-treated after cold work, and suggestions are made of the factors leading to their appearance.

Finally, a tentative equilibrium diagram of the 12% chromium, 12% nickel alloy is shown for varying small amounts of carbon, based on the results of experiment and on existing diagrams for the 18% chromium, 8% nickel alloy.

THE iron–nickel–chromium steels are usually regarded as non-magnetic, since, for all practical purposes, they remain fully austenized when quenched from a sufficiently high annealing temperature. When subjected to cold work, however, as for example by drawing into fine wires, they exhibit a considerable degree of ferromagnetism, with inductive coercivities ($_BH_c$) extending to upwards of 200 oersteds, and remanence values up to 6000 gauss or more with the lower coercivities.

This paper describes how the magnetic properties have been found to change in fine wires of these alloys after different degrees of cold work and also after subsequent heat-treatment. In studying the observed results a method of analysis has been employed similar to that described by Richer[1] in his survey of the domain theory of ferromagnetism and its application to polycrystalline electrical sheet steels, and this method has given very satisfactory results. It has been found possible to form an idea of the structural changes taking place in these fine wires, which investigation by other methods should be able to confirm or deny.

(1) MAGNETIC PROPERTIES OF IRON–NICKEL–CHROMIUM WIRES

Method of Measurement

With apparatus which has been described elsewhere[2] it is possible to examine on a cathode-ray oscilloscope the magnetic properties of single wires with field strengths along the axis of the wire up to 1000 oersteds. The apparatus is extremely sensitive, and remanence values can be read to an accuracy of some 10% and coercivities to within 5%. Two curves are obtainable ; (*a*) one showing the rate of change of magnetic intensity, $dJ/dt - H$, which by a simple calculation can be transformed into one showing the differential susceptibility, $dJ/dH - H$, and (*b*) the hysteresis loop, $4\pi J - H$, which by addition of a vertical H component becomes the $B - H$ loop. The former curve is particularly valuable in disclosing marked departures from a homogeneous structure giving rise to appreciable "jumps" in magnetization, even when the latter are still too small to be noticeable on the hysteresis loop. The appearance of these discontinuities has been referred to elsewhere.[3]

Experimentally Observed Characteristics

A very large number of individual samples of wires of varying tensile strengths has been examined in the course of the past two years, although much of the earlier work was carried out with considerably less sensitive apparatus than that referred to above.

Owing to the fact that often little was known until recently of many of the details of the drawing processes, *e.g.*, annealing temperature, diameter of the wire at last anneal, number of dies through which it was drawn to reduce it from this diameter to the standard final diameter of 0·004 in., there was some fluctuation in the magnetic values obtained for wires of the same composition and tensile strength. With fuller knowledge, however, it has been found possible to form general conclusions, shown graphically in Fig. 1, for the alloy with a composition as follows :

Nickel	Chromium	Carbon	Iron
12%	12%	0·1% approx.	Remainder

The arrest at approximately 75–77% area reduction, both in the fall of coercivity ($_JH_c$), and in the rise of remanence, seems to be a genuine fact after full allowance has been made for the possible vagaries in drawing referred to above.

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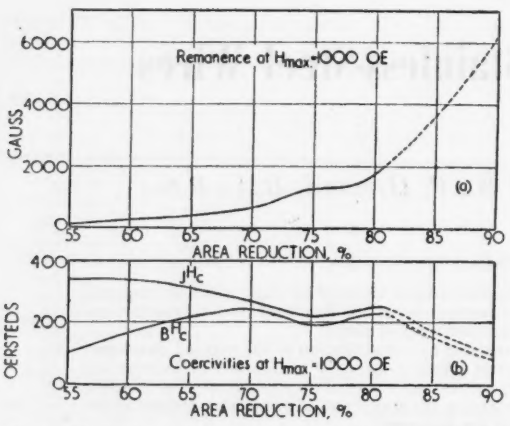

Fig. 1—Variation of (*a*) remanence and (*b*) coercivity with increasing amount of cold work for stainless-steel wires of composition: 12% nickel, 12% chromium, 0·1% carbon, remainder iron

A considerable number of samples of alloys with a composition as follows :

Chromium	Nickel	Carbon	Iron
18%	8%	0·1%	Remainder

has also been examined although not so evenly spread over this range of tensile strengths. This alloy hardens very rapidly under cold work so that conditions of drawing differ markedly from those for the more ductile 12/12 composition, and the resulting magnetic properties are much more sensitive to variations in these processes.

Steps have lately been taken to standardize the methods for the attainment of specified magnetic properties. At present it can be said that the general trend is much the same as with the 12/12 alloy, but the indications of the variation with the degree of cold work are not so precise.

Conclusions to be Drawn

Published literature on stainless steel[4, 5] is largely concerned with the 18/8 composition, and no study of the 12/12 alloy as such has been discovered, nor have many references to wires.[6] Such ternary constitution diagrams as have been constructed[5, 7, 8] are mainly for temperatures above 500° C. However, the available evidence is that the face-centred-cubic austenitic structure is only metastable for these alloys at room temperature, so that the " stirring " effect of cold work allows the more stable ferritic state to be assumed, at least in part. The first transformation is probably due to a martensitic structure,[5, 9, 10] thus accounting for the relatively rapid hardening of the material which is especially pronounced in the 18/8 alloy.

The process appears to be somewhat as follows : The austenitic structure is face-centred-cubic with chromium and nickel atoms occupying sites on the γ-iron lattice, apparently at random ; the relatively very few and much smaller carbon atoms will appear as interstitial impurities located either at a cube centre or at the mid-point of a cube edge,[11] thus causing some distortion of the cubic lattice. Initially, under tension, glide takes place along the close-packed (111) planes.[12] Local lattice distortions resist this glide, resulting in rupture into smaller crystallites. The relative movement of atoms along interfaces of crystallites allows the formation, in very fine dispersion along the glide planes, of iron–chromium–carbon compounds similar to cementite ; these are probably mainly chromium carbides of high chromium percentage,[13] with smaller amounts of iron carbides (true cementite). Since the crystal structure of these compounds is complex[14] they should have a marked " pegging " effect, thus giving rise to rapid hardening.

In the neighbourhood of these slip bands which delineate the glide planes, the austenite will be relatively denuded of chromium and carbon, and the release of strains consequent upon the movement of these atoms will enable the lattice in these regions to approach the more stable body-centred-cubic form proper to magnetic iron-rich iron–nickel alloys at or near room temperature. This would give rise to thin plates or laths of ferrite, either true body-centred-cubic, or nearly cubic body-centred-tetragonal (martensite), separating the austenite from the slip-bands, the structure being similar to the Widmanstätten formation of meteoric irons which is found also in precipitation-hardened alloys.[15, 16] The meteoric irons are essentially iron-rich iron–nickel alloys and in these the (110) planes and the [111] directions of the ferritic constituent (Kamacite) are parallel to the (111) planes and the [110] directions of the austenitic component (taenite),[16, 17] and from the similarity of constitution of the alloys under discussion a like crystallographic arrangement could be expected. Only after considerable tensile stress would the ferrite break away from the austenite, the two structures being at first bound together by adjustments of atomic spacing so that one zone would merge into the other. This condition also has been observed in the course of precipitation-hardening,[17, 18] and theoretical considerations have shown that thin transition zones would be subject to greater internal strains than thin sheets or plates that have broken away from the parent lattice.[19] The high coercivity at the lower tensile strengths of the wires tested may thus be explained by this type of structure, the coercivity dropping as the strains are released by the breaking away of the growing sheets of ferrite which tend to assume a more truly cubic form. The rapid hardening and acquisition of magnetic characteristics of the 18/8 alloy can be explained by the larger proportion of chromium, which allows a more rapid formation of fine carbide precipitates and quasi-martensitic ferrite.

The process of drawing tends to align [111] directions of the face-centred austenite in the direction of drawing with [100] as a subsidiary direction.[20] Thus with the formation suggested above [110] directions of the ferrite layers will tend to this direction also, which is the preferred direction of cold-drawn wires of body-centred-cubic metals such as α iron.[20]

It would therefore be expected that with increasing cold work a greater percentage of the ferrite formed would show this crystal orientation ; since such wires exhibit a " conical " structure[20] with the preferred direction most marked at the centre and near the outside, repeated drawing through dies in reducing

the cross-sectional area increases the relative volume in which the alignment approaches perfection. The resulting perpendicularity of the glide planes to the direction of drawing is the cause of the high tensile strength in this condition.

Magnetic analysis of preferred crystal orientation should provide evidence for or against the proposed type of structure outlined above. It can, however, only deal with the magnetic part of the material, and other methods, in particular the use of X-rays, would be required to give a more detailed analysis of the complete structure. It is claimed, however, that the method of analysis now to be described can be of considerable use in the general study.

(2) ANALYSIS FROM THE TECHNICAL MAGNETIZATION CURVE AND THE REMANENCE CURVE

Theory—The Method of Trichotomy

Richer,[1] in a paper which contains an extensive list of references to theoretical and experimental work, describes a method of magnetic analysis to which he has applied the name "Trichotomy." The technical magnetization curve from zero field to the point of maximum susceptibility ($K = J/H$), *i.e.*, the point of contact of the tangent from the origin, is divided into three portions at field strengths which are in the ratio $1 : \sqrt{2} : \sqrt{3}$ respectively.

For a material possessing no preferred domain orientation, these values of H may be taken to mark the approximate completion of 180° reversals of domain magnetization for those domains of which the spontaneously magnetized directions (in the demagnetized condition of the material) are such that the direction of the applied field is most nearly parallel to a [100], [110], and [111] crystal direction respectively, so that they are given the symbols $H_{o[100]}$, $H_{o[110]}$, and $H_{o[111]}$, in ascending order of magnitude. For such materials the most nearly straight portion of the curve is found to lie between $H_{o[100]}$ and $H_{o[110]}$, and any marked variation from this general rule indicates a degree of preferred orientation which can usually be satisfactorily accounted for by known conditions of cold work. The observed smoothness of the curve is due to the variation of domain boundary conditions which permits reversals of any one particular type of domain group to occur at different values of critical field H_o,[21] but the total increment in J due to reversals of this group will be of the same order as if they all took place simultaneously at the calculated point of completion of the group reversals.

The three observed increments are then used as a means of estimating the percentages of crystal orientation in the three named directions relative to that of the applied field, on the theoretical basis that with equal volumes in these three directions the increments should be proportional to 1, $\sqrt{2}$, and $\sqrt{3}$ respectively. Using these results and an estimate of the saturation intensity J_s, the theoretical increment by 180° reversals can be calculated. In the examples quoted by Richer this turns out to be considerably in excess of that occurring up to the point $H_{o[111]}$, and he considers the deficiency to be due to "secondary" reversals (in contradistinction to the "primary" reversals of the steep part of the curve) which represent major structural differences or lattice distortions entailing higher critical fields to initiate domain reversals, and exhibiting no trichotometric characteristics. The completion of all 180° reversals, both primary and secondary, is shown by the "knee point" ($H = H_K$, $J = J_K$), the approximate position of which is given by the following two considerations: (1) The slope of the curve at the point must be approximately twice the initial slope at $H = 0$; (2) the value of J_K must be very little less than the remanent value J_r, since as a general rule the 90° turns occurring above this value of H are in the main reversible. An estimate of the position of the "translational end point" ($H = H_t$, $J = J_t$), marking the completion of 90° turns as well as 180° reversals, can also be made, using the calculated proportions of the crystal orientation.

The foregoing is a brief outline of the main points of Richer's theory. His very full paper[1] should be studied for the detailed development and the structural implications involved. Some modifications to suit the very different type of material considered in this paper are indicated below.

Modifications in the General Theory—Use of the J_r—H Curve

The general theory outlined above pre-supposes an equal partition of the directions of spontaneous domain magnetization (in the demagnetized state of the material), among the six possible [100] directions of the cubic crystal lattice. As Richer points out, however, the work of Brailsford and Martindale[22] on changes in magnetostriction with variation in preferred crystal orientation shows that cold work tends to produce preferred domain orientation superimposed on preferred crystal orientation; *i.e.*, domains with directions parallel and anti-parallel to the direction of the applied field grow at the expense of those with directions in the four at right-angles to this. This must have some effect, not only on the relative increments in J, owing to 180° reversals and 90° turns, but also on the extent and magnitude of secondary reversals, since domain boundary conditions and lattice strains must be much modified. Such modifications must be borne in mind and allowed for, where possible, when using this method to analyse material of known or strongly surmised preferred crystal orientation.

In analysing from the technical magnetization curve, the increments in J due to 90° turns are neglected in comparison with the large increments due to 180° reversals and high saturation values J_s for electrical sheet steels. With materials of much lower saturation values, however, the differences will not necessarily be so pronounced, and the J_r–H curve would seem to be more satisfactory. This is a curve of irreversible processes only, which must be very largely composed of 180° reversals. The two curves have very much the same shape, and experience shows that not only are the steepest portions of both covered by very nearly the same values of H, but also that the tangents to both from the origin have points of contact at almost identical H values. The degree of accuracy obtainable, necessarily qualitative rather

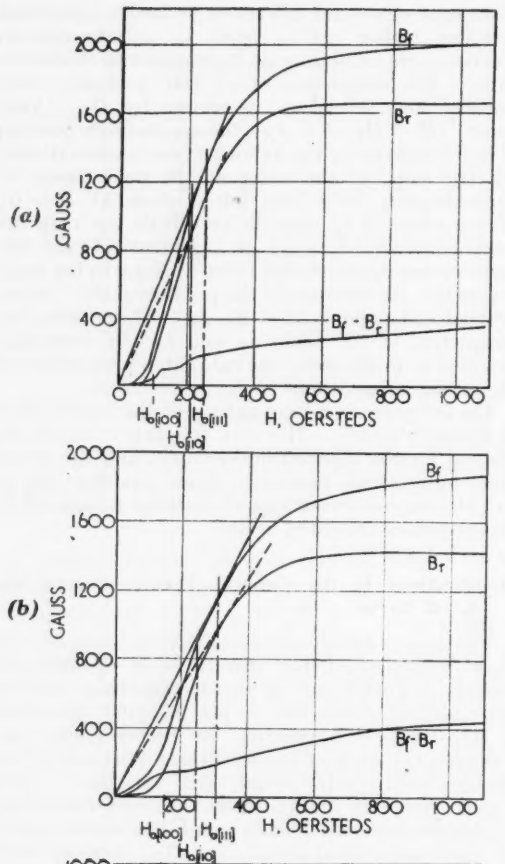

Fig. 2—Normal ferric induction and remanence curves for 0·004-in. dia. stainless-steel wires drawn to tensile strengths of (*a*) 117 tons/sq. in., (*b*) 112 tons/sq. in., (*c*) 150 tons/sq. in., showing the method of analysis; (*a*) and (*b*) 12/12 stainless steel, (*c*) 18/8 stainless steel

than highly quantitative, must be of the same order in both, and the fact that the remanence curve deals with irreversible processes only is a great argument in its favour. If the two curves are plotted together the differences between them from point to point will show the increments due to reversible processes only (*i.e.*, 90° turns and rotations). This procedure is adopted in the practical examples which follow.

Practical Examples—Stainless-Steel Wire

Example (*a*)—In Fig. 2 (*a*) are shown the magnetization and remanence curves for a sample of 12/12 stainless-steel wire, 0·004 in. in dia. and with a tensile strength of 117 tons/sq. in. The upper curve, labelled B_f, represents the so-called "ferric induction," *i.e.*, B–H or $4\pi J$, for variations in exciting field H from 0 to 1000 oersteds. It is actually the plot of the variation of the maximum values of $4\pi J$ with 50-cycle alternating fields of progressively increasing strengths. The curve labelled B_r shows the variation of remanence or $4\pi J_r$, the irreversible magnetization, obtained in the same way. The lowest curve shows the difference between the ordinates of the two upper curves, which is a measure of the reversible magnetization.

It can be seen that the tangents from the origin to both curves have points of contact at approximately $H = 250$ oersteds, and that both curves are practically straight lines between $H = 100$ and $H = 200$ oersteds. Hence the theory gives $H_{o[111]} = 250$. For a material with no preferred crystal orientation the theory gives $H_{o[100]} : H_{o[110]} : H_{o[111]} = 1 : \sqrt{2} : \sqrt{3}$, *i.e.*, $H_{o[100]} = 144$, $H_{o[110]} = 204$. From Fig. 2 (*a*) it can be seen that the upper end of the straight part of each curve does occur at the latter value of H in accordance with theory, but that the former is the value at about the middle of the straight part, while the theory postulates the lower end. However, for a hard-drawn wire such as this, a large preponderance of the body-centred-cubic crystals of ferrite aligned in the [110] direction, with a correspondingly small number aligned in the [100] and [111] directions, is to be expected.

As a basis of analysis, therefore, it is reasonable to assume that $H_{o[100]} = 100$, $H_{o[110]} = 204$, and $H_{o[111]} = 250$ oersteds. Using these figures, the analysis proceeds as follows :

$B_{f[100]} = 175$, $B_{f[110]} = 1025$, $B_{f[111]} = 1300$ gauss
$B_{r[100]} = 125$, $B_{r[110]} = 875$, $B_{r[111]} = 1100$ gauss

The second line gives the irreversible part of the magnetization. The reversible part is the difference $B_f - B_r$, giving the three values 50, 150, and 200 gauss respectively.

The percentage contributions of the three hypothetical crystal groups are shown below for both curves, for comparison, but the figures for the B_r curve only will be used in the later analysis.

Crystal Group	Contribution to $B_{f[111]}$ (reversible and irreversible) Gauss	%	Contribution to $B_{r[111]}$ (primary reversals only) Gauss	%
[100]	175	13·5	125	11·4
[110]	850	65·4	750	68·2
[111]	275	21·1	225	20·4
	1300	100·0	1100	100·0

The contributions by reversible processes—the differences between the two sets of figures given above—with the probable type of process for each group are as follows :

Crystal Group	Reversible Contribution, gauss	Type of Process
[100]	50	90° turns only
[110]	100	Mainly 90° turns ; some rotations
[111]	50	

On the theory of equi-partition among the six possible [100] crystal directions of the spontaneously magnetized domain directions, the contributions of equal crystal-group volumes would be in the ratio of $1 : \sqrt{2} : \sqrt{3}$. On this assumption, therefore, the estimated crystal-group distribution is calculated from the contributions to $B_{r[111]}$ as follows :

Crystal Group	Estimated Crystal-Group Distribution Proportional		%
[100]	$11 \cdot 4/1$	$= 11 \cdot 4$	$16 \cdot 0$
[110]	$68 \cdot 2/\sqrt{2}$	$= 48 \cdot 2$	$67 \cdot 5$
[111]	$20 \cdot 4/\sqrt{3}$	$= 11 \cdot 8$	$16 \cdot 5$
		$71 \cdot 4$	$100 \cdot 0$

These values are of the order to be expected, so that the analysis is satisfactory so far, despite the fact that no account has been taken of probable preferred domain orientation.

On the same simplified assumption, the theoretical contributions by primary reversals to the saturation value of B_f, which from Fig. 2 (*a*) is of the order of 2100 gauss, are calculated as follows :

Crystal Group	Percentage of Total	Theoretical Contribution, gauss	
[100]	$16 \cdot 0$	$2100 \times 0 \cdot 16 \times \frac{1}{3}$	$= 112$
[110]	$67 \cdot 5$	$2100 \times 0 \cdot 675 \times \sqrt{2}/3$	$= 668$
[111]	$16 \cdot 5$	$2100 \times 0 \cdot 165 \times \sqrt{3}/3$	$= 200$
	$100 \cdot 0$		980

This result is 120 gauss (11%) less than the observed value of $B_{r[111]} = 1100$ gauss. The most probable explanation is that there is a considerable degree of preferred domain orientation due to cold work (and also possibly in part to the method of demagnetization). Brailsford and Martindale[22] found that in a cold-rolled silicon sheet steel, in which investigation had shown that more than two-thirds of the grains had a [100] direction parallel to the rolling direction, the volume of domains spontaneously magnetized either parallel or anti-parallel to the direction of rolling amounted to some $0 \cdot 54$ of the total instead of the $\frac{1}{3}$ of random distribution. Thus the average volume of a pair of mutually anti-parallel domains in a direction at right-angles to the rolling direction would be $0 \cdot 23$ instead of $\frac{1}{3}$; and. as a rough basis of estimation, the assumption that this is of the correct order for any other direction of rolling results (for the [110] direction) in $0 \cdot 77$ for the volume of all domains with directions in the plane of the rolling direction (or drawing direction).

From these figures the following can be obtained, the ratio of the theoretical contribution by equal crystal-group volumes with this domain distribution being $0 \cdot 54 : 0 \cdot 77/\sqrt{2} : 1/\sqrt{3}$.

Crystal Group	Estimated Crystal-Group Distribution Proportional		%
[100]	$11 \cdot 4/0 \cdot 54$	$= 21 \cdot 1$	$11 \cdot 6$
[110]	$68 \cdot 2 \times \sqrt{2}/0 \cdot 77$	$= 125 \cdot 2$	$69 \cdot 0$
[111]	$20 \cdot 4 \times \sqrt{3}$	$= 35 \cdot 3$	$19 \cdot 4$
		$181 \cdot 6$	$100 \cdot 0$

Again these values are of the order to be expected, particularly that for the [110] group.

From these percentages and the new estimate of partition of domain volumes, the following figures can now be determined :

Crystal Group	Percentage of Total	Theoretical Contribution, gauss	
[100]	$11 \cdot 6$	$2100 \times 0 \cdot 116 \times 0 \cdot 54$	$= 131$
[110]	$69 \cdot 0$	$2100 \times 0 \cdot 69 \times 0 \cdot 77/\sqrt{2}$	$= 789$
[111]	$19 \cdot 4$	$2100 \times 0 \cdot 194/\sqrt{3}$	$= 235$
	$100 \cdot 0$		1155

Here, not only the total, but also the individual contributions are more nearly equal to the observed values, being in every case rather too large, whereas on the assumption of equi-partition each was considerably too small. This lends support to the probability of the explanation offered earlier. Indeed, by assuming $0 \cdot 26$ for the average volume of a pair of mutually anti-parallel domains in a direction at right-angles to the direction of drawing (instead of $0 \cdot 23$ as in the previous case and $\frac{1}{3}$ for random distribution) the following extremely close results are obtained, the crystal-group distribution now being $12 \cdot 5\%$, $68 \cdot 8\%$, and $18 \cdot 7\%$ respectively.

Crystal Group	Percentage of Total	Theoretical Contribution, gauss		Observed, gauss
[100]	$12 \cdot 5$	$2100 \times 0 \cdot 125 \times 0 \cdot 48$	$= 126$	125
[110]	$68 \cdot 8$	$2100 \times 0 \cdot 688 \times 0 \cdot 74/\sqrt{2}$	$= 756$	750
[111]	$18 \cdot 7$	$2100 \times 0 \cdot 187/\sqrt{3}$	$= 227$	225
	$100 \cdot 0$		1109	1100

In spite of the conjectural nature of some of the assumptions made, the results obtained are such as to justify the claim that this method of analysis gives results of the right order of magnitude. In this example, *for the primary form of ferrite* present in this alloy, after the degree of cold work indicated, and without subsequent heat-treatment, more than two-thirds of the crystals are aligned with a [110] direction nearest to the direction of drawing, and in the process of drawing such preferred domain orientation has been acquired that the volume of domains with spontaneously magnetized directions perpendicular to the direction of drawing has been reduced by some 20% or more from the ideal proportions of perfectly random orientation.

Very striking support of this claim is given by the next example.

Example (*b*)—The curves for a sample of 12/12 stainless-steel wire, $0 \cdot 004$ in. in dia. and having a tensile strength of 112 tons/sq. in., are shown in Fig. 2 (*b*), and are of the same form as in the previous example. As is to be expected with less cold work, the apparent saturation value of B_f is somewhat less at 1900 gauss, as is the maximum value of B_r at approximately 1420 gauss. At the same time the maximum susceptibility occurs at a higher value of $H_{o[111]}$, *viz.*, 305

oersteds, compared with 250 oersteds. Hence the theoretical values of $H_{o[100]}$ and $H_{o[110]}$ are 176 and 249 oersteds respectively, but for the same reasoning as before the former is taken to be 150 oersteds while the latter is retained as 250 oersteds.

The contributions to $B_{r[111]}$ by the hypothetical crystal groups are in order [100] 150 gauss, [110] 590 gauss, [111] 230 gauss, giving a total $B_{r[111]} = 970$ gauss. Calculating as before, the estimated crystal distribution, on the basis of equi-partition of directions of spontaneous domain magnetization, is in the same order 21·5%, 59·5%, and 19%, which is reasonable, the amount of drawing being less than in the first example (six passes instead of eight). On the same basis the theoretical contributions to $B_{fs} = 1900$ gauss are in order 136, 532, and 208 gauss (total 876 gauss), each being less than the observed results, the reduction in the total being 94 gauss compared with 120 gauss in the previous example. In conformity with the idea that less cold work would produce less preferred domain orientation, it is to be expected that a higher proportion of the domain volume would have spontaneous directions perpendicular to the direction of drawing. Thus, trying the value 0·28 (compared with 0·26) for the volume of a pair of mutually anti-parallel domains perpendicular to the drawing direction, the following most satisfactory results are obtained :

Crystal Group	Percentage of Total	Theoretica Contribution, gauss		Observed, gauss
[100]	18	$1900 \times 0{\cdot}18 \times 0{\cdot}44$	$=150{\cdot}5$	150
[110]	61	$1900 \times 0{\cdot}61 \times 0{\cdot}72/\sqrt{2}$	$=590$	590
[111]	21	$1900 \times 0{\cdot}21/\sqrt{3}$	$=230{\cdot}5$	230
	100		971	970

Example (*c*)—As a further example the case may be cited of an 18/8 stainless-steel wire, 0·004 in. in dia. and having a tensile strength of 150 tons/sq. in. The degree of cold work was unknown, but in view of the rapid hardening of this alloy under cold work, it was to be expected that the area reduction since the last anneal would be less than that of the two previous examples of 12/12 wires of lower tensile strengths. Hence a lower degree of preferred crystal orientation and possibly of preferred domain orientation could also be looked for. The curves for this sample are given in Fig. 2 (*c*), and the analysis shows how well these expectations were realized. The numbers on the vertical scale of gauss are probably somewhat high, but since the calculations in the analysis are entirely worked on proportional increases this does not affect the validity of the results.

From both curves, $H_{o[111]} = 200$ oersteds, from which theoretically $H_{o[110]} = 163$ oersteds and $H_{o[100]} = 115$ oersteds. As before, the former theoretical value is reasonable while the latter might well be lowered to 100 oersteds, or even less.

The contributions to $B_{r[111]}$ by the hypothetical crystal groups are respectively [100] 1000 gauss, [110] 2200 gauss, and [111] 1050 gauss, giving a total $B_{r[111]}$ of 4250 gauss. Hence, on the basis of equi-partition of directions of spontaneous domain magnetization, the estimated crystal distribution is, in the same order, 31·6%, 49·2% and 19·2%. Thus the expectation of probably less cold work with a consequent reduction in the amount of preferred crystal orientation in the [110] direction is so far borne out.

On the same basis the theoretical contributions to the saturation value of B_f (estimated at 9500 gauss) are respectively [100] 1001 gauss, [110] 2204 gauss, and [111] 1053 gauss, the total being 4258 gauss.

Here again the agreement between calculated and observed figures is extremely close and cannot be entirely fortuitous. The evidence from this analysis is that for this sample approximately half of the primary magnetic constituent is aligned with [110] crystal directions nearest to the direction of drawing, while there is no appreciable preferred domain orientation superimposed upon this crystal orientation. Both of these results are of the order to be expected, having regard to the probable degree of cold work to which the sample had been subjected.

These three examples show that this method of analysis when carefully applied can give a reasonable estimate of the crystallographic arrangement of the main magnetic constituent of fine wires of cold-worked iron–nickel–chromium alloys, but so far no consideration has been given to the magnetization by irreversible processes above the value at the point of maximum susceptibility—the " knee " of the curve.

In the example of " with and against " rolled electrical sheet steel analysed by Richer,[1] the theoretical contribution to the saturation value by the hypothetical crystal groups was considerably in excess of the observed contributions by all processes up to this point, and the deficiency was ascribed to " secondary reversals " of domains of the same magnetic constituent which require higher field strengths to effect 180° reversals owing to more difficult boundary conditions at domain boundaries, or crystal boundaries and external faces, or to major lattice distortions. In the wires analysed here, which have been worked very differently and are of a considerably more complex structure, a reasonable estimate of preferred domain orientation gives a theoretical contribution by 180° reversals substantially equal to the irreversible magnetization, up to the same reference point. Possible causes of the additional irreversible magnetization occurring at higher fields are :

(*a*) The occurrence of different spatial relationships between the ferrite and austenite, the constitution remaining the same.

(*b*) The appearance of another magnetic constituent, possibly a different phase of the same constitution.

(*c*) The irreversibility of some 90° turns.

Full discussion of these points is given in section (5). At present the additional irreversible magnetization will be referred to as the contribution by " secondary reversals," and its variation as between the three examples already analysed is considered below :

Example (*a*) (*Fig.* 2 (*a*))

	Gauss
Br (max.)	= 1660
Primary contribution	= 1100
Secondary contribution	= 560

Secondary = 50·9% of primary or 33·7% of total.

Example (*b*) (*Fig.* 2 (*b*))

	Gauss
B_r (max.)	= 1420
Primary contribution	= 970
Secondary contribution	= 450

Secondary = 46·4% of primary or 31·7% of total.

Example (*c*) (*Fig.* 2 (*c*))

	Gauss
B_r (max)	= 5700
Primary contribution	= 4260
Secondary contribution	= 1440

Secondary = 39·8% of primary or 25·3% of total.

It would thus appear that increasing cold work gives rise to a larger proportion of secondary reversals.

Assuming the hypothetical crystal-group distribution used in the final analysis of each of the three samples, the theoretical contributions to the saturation value of B_f by 90° turns are respectively 402, 421, and 3104 gauss. The values for the first two (12/12 alloy) are high compared with the contribution by irreversible processes shown in Figs. 2 (*a*) and 2 (*b*), and the last is somewhat higher than would be expected if the 90° turns were entirely reversible for the 18/8 alloy (Fig. 2 (*c*)). There is thus evidence of some degree of irreversibility of 90° turns, which at first sight appears to be more pronounced with higher nickel content.

(3) USE OF THE HYSTERESIS LOOP

It is possible by projecting a photograph of a hysteresis loop on to squared paper, to make a somewhat rough and ready analysis of the material on similar lines from the following considerations:

(i) It is found in practice that the tangent to the uprising curve from the lower B_r point makes contact at approximately the same value of H as for that from the origin to the technical magnetization curve (*see* Fig. 3).

(ii) The contributions by 180° reversals should be approximately double those in the latter curve, since in cyclic magnetization pairs of domains are reversed together instead of only one of a pair.

It is impossible by this method to isolate irreversible processes, and the results obtained can be expected only to indicate which crystal direction, if any, is preferred, without any very accurate figures of proportionality. With actual samples of wire the full method, described in section (2) is much to be preferred.

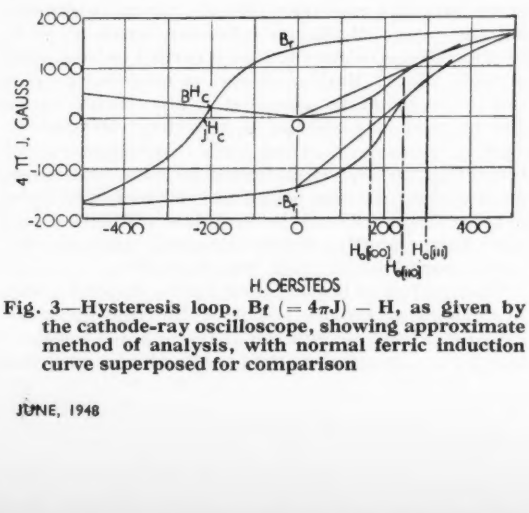

Fig. 3—Hysteresis loop, B_f ($= 4\pi J$) − H, as given by the cathode-ray oscilloscope, showing approximate method of analysis, with normal ferric induction curve superposed for comparison

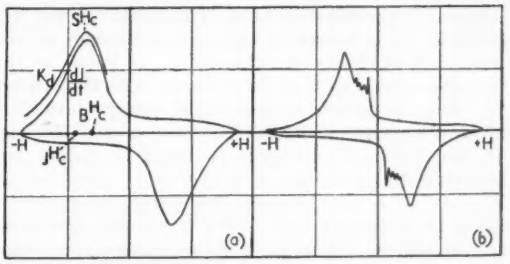

Fig. 4—Differential susceptibility curves as shown by the cathode-ray oscilloscope. (*a*) Smooth type of curve indicating well-annealed material, and (*b*) curve with pronounced irregularities indicating heterogeneity of structure

The principal use of the hysteresis loop in analysis consists in giving the value of the coercive force for comparison with the values of critical field H_o. Using the $4\pi J - H$ loop (*i.e.*, the B_f loop) it is found that the intensity coercivity $_JH_c$ varies very little as the exciting field H increases from a value for which B_r is near its maximum. The values at $H_{max.} = 1000$ oersteds for the materials here discussed are very little more than at $H_{max.} = 500$ oersteds, and may be considered to be the same as if the material were saturated.

For example (*a*) (*see* section (2)), $_JH_c = 260$ oersteds, which is rather higher than $H_{o[111]}$; for example (*b*) it is 255 oersteds, just above $H_{o[110]}$, and for example (*c*) it is 150 oersteds which is just less than $H_{o[110]}$. All are taken at $H_{max.} = 1000$ oersteds.

The inductive coercivity $_BH_c$ can be obtained from the same loop if required, by noting the point of intersection with the straight line $4\pi J = -H$.

(4) USE OF THE DIFFERENTIAL SUSCEPTIBILITY CURVE

With the magnetic testing apparatus described in section (1), the simplest trace obtained on the cathode-ray oscilloscope is one showing the time variation of intensity dJ/dt against changing values of field H. An integrating circuit is required to produce the hysteresis loop. An example of this differential curve is given in Fig. 4 (*a*), which shows a pronounced peak indicating that there is a definite value of H at which the volume of domains undergoing instantaneous 180° reversals is a maximum. The true differential susceptibility curve ($K_d = dJ/dH$) is obtained from this curve by dividing by cos ωt (since $H = H_{max.} \sin \omega t$, ω being 2π times the frequency of the alternating magnetizing field), and is also shown in Fig. 4 (*a*). It can be seen that the latter curve peaks at a slightly higher value of H than the former, but in this example the value of $H_{max.}$ was no more than 500 oersteds and it is found that as $H_{max.}$ approaches saturation values the two peaks tend more and more to occur together.

It is also found that there is very little change in the H value of the dJ/dH peak as $H_{max.}$ varies, especially at the higher values of the latter, and that this peak, which represents the maximum steepness of the hysteresis loop, occurs at values of H which are practically identical with those at which the

technical magnetization and remanence curves are steepest. It is therefore convenient to refer to the value of H at this peak (when $H_{max.}$ is large) as the "specific coercivity" of the material, with the symbol ${}_SH_c$, since it admits of a physical interpretation on the domain theory, while the more usual ${}_BH_c$ and ${}_JH_c$ are the field strengths required to reduce the induction and intensity respectively to zero; or, in the case of cyclic magnetization, the strengths at which they change sign. For a smooth hysteresis loop of which each branch approximates to a cubic algebraic curve the value of ${}_SH_c$ was found to be the harmonic mean of ${}_BH_c$ and ${}_JH_c$. Assuming linearity of the loop between the latter points this gives $\mu = \frac{1}{2}$, $K = \frac{3}{8\pi}$ at the ${}_SH_c$ point.

A great advantage of this curve is that it will show irregularities of magnetization even when the latter are too small to appear as step discontinuities in the hysteresis loop. An example showing well-marked irregularities is given in Fig. 4 (*b*). Such irregularities of magnetization can be due only to the presence of "knots" of material with outstanding differences from the average, such as (*a*) aggregates of the same constitution subject to very different conditions of internal strain,* (*b*) inclusions in the main structure of material of a different constitution, and (*c*) inclusions of the same material but of different magnetic phase. These possible causes are discussed later in detail.

(5) THE SIGNIFICANCE OF PRIMARY AND SECONDARY REVERSALS

If the structure developed by cold work is of the type suggested in section (1), the thin "plates," "sheets," or "laths" referred to there will take the form of fibres in cold-drawn fine wires, which is the well-known structure exhibited by X-ray analysis.[23] The thicker the plates the longer the fibres in the direction of drawing, as the former tend to align themselves perpendicularly to this direction.

An individual fibre may well be of the size of a single domain, the maximum volume of which is of the order of 10^{-9} c.c.[24] Such a volume is contained in a length of about 10^{-4} cm. of these wires, which have a diameter of 0·004 in., *i.e.*, a cross-sectional area of $8{\cdot}1 \times 10^{-5}$ sq. cm. Since the cross-sectional area of an individual fibre must be very much less than that of the wire, it can be many times longer than this and still have a volume well below the maximum size of one domain.

In this connexion the conclusion of Schulze,[25] that magnetic viscosity is a function of frequency, on the assumption of thread-like domains, is of interest in this study of magnetization by 50-cycle alternating fields.

Treating each fibre as a single domain, the longer fibres of the thicker plates would in general exhibit less self-demagnetization† than those of shorter length relative to their other dimensions, and would thus require higher critical fields H_0 to initiate reversals, while their contribution to the total magnetization would be relatively more. Conversely, small particles of ferrite "embedded" in more or less isolated positions in the austenite would be expected to show larger amounts of self-demagnetization, and thus to require lower values of H_0 with smaller individual contributions to the total magnetization. On this conception the "secondary" magnetization discussed in section (3) might well be in part that due to the more continuous plates of ferrite, and the "primary" that mostly exhibited by more broken-up magnetic lamellae. The former would be expected to be relatively more pronounced with larger degrees of cold work. The results of experiment given at the end of section (2) are in qualitative agreement with this idea.

There is so far no direct evidence from these curves of the existence of a markedly different magnetic constituent or different magnetic phase of the same general constitution. Any large amounts of either might be expected to give rise to obvious irregularities of magnetization of which there are no traces observable in these examples.

The evidence for irreversibility of some of the 90° turns is, however, strong, and is not dependent upon the assumption of preferred domain orientation. It must therefore be considered that this is a real phenomenon, and not merely a spurious effect resulting from the empirical nature of the analysis. That the effect is apparently more pronounced with the alloy of higher nickel content may perhaps be associated with the well-known "sluggishness" in attaining equilibrium states exhibited by nickel-containing alloys.

The foregoing paragraphs indicate some of the lines of further study by other means which this method of magnetic analysis can suggest. As stated before it is not claimed that the method can give a complete picture of the structure of the material, but that its results should be of value in the correlation of the evidence offered by many different types of investigation.

(6) EFFECTS OF HEAT-TREATMENT

Observed Effects on Magnetic Properties

With the primary object of obtaining higher values of the inductive coercivity ${}_BH_c$, as a means of improving the ratio ${}_BH_c/B_r$, an extensive series of heat-treatment experiments has been carried out on wires of these alloys. Marked changes in magnetic properties were found to occur at temperatures above 400° C., and in particular in the range 500–600° C. This is the range in which earlier investigators had found that rapid precipitation of carbides takes place, mainly along the slip planes in cold-worked samples of these alloys, whereas the unworked austenitic alloys have been stated to become magnetic while precipitation occurs at the grain boundaries.[27]

One method of heating used was to suspend a wire in a cylindrical furnace, a short section near the upper closed end being maintained at the required temperature by an electrical method. After being quenched

* This would include the incidence of relatively short individual domains, exhibiting considerable self-demagnetization (*see* section (5)).

† Acknowledgments are due to Professor Stonor for this idea of the effects of the self-demagnetization of individual domains of varying size. The importance of varying size in domains was first pointed out by Professor Stonor many years ago.[26]

by dropping into water such wires exhibit a marked temperature gradient of magnetic variation along their length, the whole sequences of changes in the differential curve described below being exhibited as a continuous process as the wire is passed through the magnetizing coil of the testing apparatus.

As was to be expected, " time at temperature " was found to be an important factor in obtaining any specific combination of magnetic values. A generalized summary of the observed effects is given below :

(*a*) *Remanence* showed a slight rise at first followed by a fairly rapid fall.

(*b*) *Coercivity* also increased at first, but for the same length of time at temperature reached its maximum at a higher temperature than that giving maximum remanence ; thereafter it, too, fell rapidly.

(*c*) The 18/8 alloy required higher temperatures than the 12/12 to produce the effects in (*a*) and (*b*) with the same length of time at temperature.

(*d*) At 600° C., or rather less, the 12/12 alloy was virtually non-magnetic as judged by the hysteresis loop, and the same was true for the 18/8 at around 700° C. However, in this state the differential susceptibility curve showed a small peak at $H = 60$–70 oersteds, the original curve of the form shown in Fig. 4 (*a*) having completely collapsed.

(*e*) At higher temperatures there was some recurrence of magnetism, very small and almost rectangular hysteresis loops being formed with remanence values of the order of 100 gauss, and coercivities, as indicated by the differential curves which now consisted of a single sharp peak, at H values gradually falling to about 30 oersteds.

(*f*) The 12/12 alloys were apparently fully austenized at 800–850° C., but in those of the 18/8 composition some slight magnetism was still apparent at 900° C.

The above results were obtained by heating in general for 5 min. at any one temperature followed by a water-quench. Changes of the same order were observed with longer times of heating at somewhat lower temperature.

The magnetic changes are well displayed by the differential susceptibility curve. The bulge at first rises, indicating the increase of slope of the hysteresis loop with increased remanence. As it subsequently falls, the peak moves to higher values of H, thus showing the increase of specific coercivity ${}_{S}H_c$. With further rise of temperature a subsidiary bulge begins to appear at a lower value of H, which later begins to move to still lower values as the original bulge collapses and the newer sharpens. Eventually, the secondary peak alone remains. At still higher temperatures this isolated peak increases temporarily in intensity, and moves slowly to still lower values of H before completely vanishing. Photographs of these changes are given elsewhere.[2]

(*Note.*—In reality the " isolated peaks " consist of a cluster of needle-like peaks centred round one of maximum height. This effect can be seen with a sufficient expansion of the H scale, and has also been noted all round the main bulge of the K_d curve for an unheated, highly worked 18/8 wire. The individual

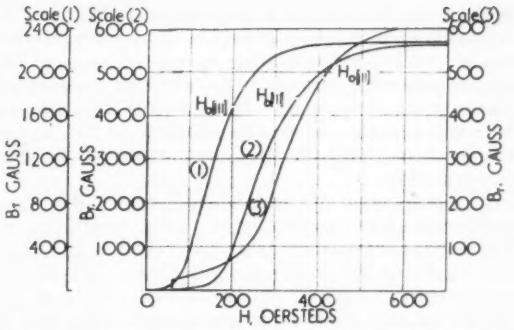

Fig. 5—Remanence curves for an 18/8 stainless-steel wire: (1) as-drawn, (2) and (3) after successive stages of heat-treatment

" needles " must represent appreciable Barkhausen discontinuities.)

Results of Analysis from Remanence Curves

In Fig. 5 are shown the remanence curves obtained from three points on a wire exhibiting such a heat gradient. This wire is the 18/8 alloy of example (*c*), (section (2)), heated for 15 min. at 700° C. The remanence curve of Fig. 2 (*c*) is here reproduced as curve (1), representing the unheated condition, for comparison with curve (2), the condition when the remanence has been more than halved, and curve (3), the condition near the hottest part of the furnace. The steep step at $H = 60$ oersteds in the last curve corresponds to a very sharp peak on the differential susceptibility curve. The increase in the value of $H_{o[111]}$ (with, as a natural consequence, higher coercivity) as the remanence falls is well brought out in these curves.

Curves (2) and (3) were analysed in the same way as the examples worked out in section (2). The resulting estimates of percentage crystal-group orientation are given below, together with those calculated in example (*c*) for curve (1).

Crystal Group	Estimated Distribution, % (1)	(2)	(3)
[100]	31·6	29·8	32·7
[110]	49·2	50·7	47·0
[111]	19·2	19·5	20·3

The results for each curve are of the same order of magnitude, thus clearly indicating the magnetization of a similar material in each case, but of progressively smaller amounts as shown by the falling remanence. Presumably the reduction in the amount of ferrite is due to the partial re-dissolving of the products of cold work, the energy from the applied heat assisting a certain amount of self-annealing along the boundaries of crystallites of opposed phases (austenite and ferrite) on the lines of the " foam structure " suggested by Bragg.[28] This would tend to restore the transition zones giving rise to higher coercivity suggested in section (1) as the probable structure after relatively little cold work.

The apparent initial increase in [110] crystal orientation and the later more pronounced decrease, if of real significance and not merely variations due to the empirical nature of this method of analysis, would seem to indicate that the first result of the added

heat energy is to allow a more natural alignment to crystallites which had been held back by other internal strains, while further heating overcomes some of the strains induced by drawing, thus allowing a somewhat more random orientation. If this is true, there should be some lowering of tensile strength at the higher temperatures, and this has been observed in wires of both alloys.

The proportion of "secondary" irreversible magnetization falls progressively with treatment at increasing temperature. For curve (1) it is 25·3% of the total, for curves (2) and (3) 21·3% and 17·6% respectively. This is consistent with either of the origins of this form of magnetization suggested in section (5) both of which increase with the amount of cold work and would be expected to be reduced with the lessening of the strains caused by drawing proposed in the preceding paragraph.

General Conclusions

Some suggested conclusions as to the processes taking place have been indicated in the foregoing; other observed results not included in the analysis of the curves remain to be studied.

The appearance of an isolated peak on the differential susceptibility curve at a lower value of H, its survival when the original ferrite has apparently been completely transformed, and its temporary intensification (still with falling H) as a slight renewal of magnetism is observed, all indicate the formation, and the increase over a certain temperature range, of a new magnetic constituent which shows very different percentage volume of the material and conditions of internal strain. It was at first thought that precipitated agglomerates of carbides were themselves exhibiting magnetism, but although it is known that true cementite (Fe_3C) does so, there is no evidence that the complex chromium-rich carbides are at all magnetic. The lowered coercivity and rectangular tendency of the hysteresis loops displayed by this new constituent are strongly reminiscent of the well-known effects of applying tension to ferro-nickels with positive magnetostriction (10% up to 80% of nickel[29]), for example, in the experiments of Sixtus and Tonks[30] on the propagation of large Barkhausen discontinuities.

Noting this similarity, as well as the observations by Bain, Aborn, and Rutherford[31] of the effects of cold work upon the resistance to intergranular corrosion of heated 18/8, it is possible to form a picture of the probable processes occurring. The dissolution of the original ferrite suggested in the previous subsection could be achieved through a rearrangement of lattice positions and spacings among iron, nickel, and chromium atoms in the transition zones between the austenite and ferrite. Carbon atoms, appearing only as interstitial impurities in either lattice, would continue to precipitate along slip planes and grain boundaries, where the previously precipitated particles, acting as nuclei, would provide an ever-increasing stimulus to this process. The carbides so formed have been found to contain up to 90% of chromium,[31] so that in regions near agglomerates of such chromium-rich carbides the depletion of chromium must result in a constitution much more nearly that of a pure ferro-nickel than the ferrite formed by cold work with less precipitation. After reaching a maximum the precipitates are gradually re-dissolved, until the whole structure is austenite.

The existence of α structure as part of a two-phase field during heating through this temperature range of ferro-nickels at percentage constitutions of the probable order involved here is supported by recent investigators of these alloys.[32, 33] It is also of note that published ternary diagrams for the iron–nickel–chromium system show an $\alpha + \gamma$ phase field for both 12/12 and 18/8 compositions between 500° and 700° C. which extends up to 900° C. for 18/8,[5, 7] while by 850° C. the 12/12 alloy is pure γ.[7] The results of the magnetic observations described in this paper can thus be credibly explained in terms which are not discordant with the constitution diagrams of other investigators, even though the times of heating may not have been sufficient to attain true equilibrium.

The new magnetic constituent formed by heat-treatment must be of extremely small volume (considering the fine structure of these wires and the fact that only relatively small regions can be appreciably denuded of chromium), and it is a tribute to the sensitivity of the magnetic testing apparatus that its presence can be detected. That the constituent is very evenly distributed throughout the matrix, suggesting the precipitation of carbides along slip planes as well as at grain boundaries,[27] is indicated by the constancy of the differential susceptibility curves along the length of a wire which travels at constant speed through an oven and, after quenching, through the magnetizing coil of the testing assembly. In this respect the irregularities are very different from those occasionally found in unheated wires (Fig. 4 (*b*)), which are discussed in the next section.

(7) CAUSES OF IRREGULARITIES IN MAGNETIZATION CURVES

Irregularities in magnetization curves are departures from smoothness which, when pronounced, take the form in technical magnetization and remanence curves, and in hysteresis loops, of short almost vertical lines followed by a return to normal smoothness, and in differential susceptibility curves appear as one or more separate peaks. In practice, when the value of $H_{max.}$ is large enough to produce values of B_r near the maximum, they are always found to occur at values of exciting field below that at the steepest part of the curve. Any one irregularity may thus be regarded as the superposition of the magnetization curve of a constituent of relatively low specific coercivity ${}_SH_c$ upon that proper to the main substance under examination.

As indicated at the end of section (4) such secondary constituents could be :

(*a*) Relatively small volumes of the same main structure as the primary, but subject to different conditions of internal strain, including the case of individual domains exhibiting a different degree of self-demagnetization.

(*b*) Inclusions of a different constitution.

(*c*) Inclusions of the same constitution but of a different magnetic phase.

The last possibility seems the least likely in the

wires studied here, since, so far as is known, there is only one magnetic phase (α) for these alloys, referred to generally as "ferrite," having a body-centred-cubic, or quasi-cubic tetragonal, crystal structure.

The irregularities observed after heat-treatment, which were discussed in the last section, appear to come under category (*a*), or even (*b*), if the suggested removal of chromium and carbon in small regions of the main structure is virtually complete.

In some wires which have not been subjected to heat-treatment after cold work, irregularities have been observed which invariably show differences from those described above in that their intensity, number, and position on the H axis change continuously from point to point along the wire, whereas those produced by heat-treatment are much more uniform in all these respects. These great variations must therefore be due to marked lack of uniformity in structure.

In some British wires of normal constitution these irregularities were very similar to those found during the stage of heat-treatment between approximately 550–600° C., and subsequent enquiry showed that the wires concerned had probably not been fully austenized at the last anneal, but merely sufficiently softened for the drawing process to be continued.

In such circumstances the $\alpha + \gamma$ two-phase structure would be retained on quenching, and subsequent cold work would transform some of the γ phase. Thus the observed structure might be described as exhibiting two magnetic phases, but is more probably an example of (*a*) approaching (*b*). The lack of uniformity from point to point along the wire indicates the degree of departure from the fully austenized condition at the last anneal.

The most pronounced irregularities observed occurred in an American wire of the 18/8 class. A considerable number of peaks is shown on the differential susceptibility curve (Fig. 4 (*b*)), the variation of position and intensity of which from point to point of the wire is very marked, ranging from almost nil to long "needles." The main peaks always occur at or very near one or other of several definite values of H, indicating the recurrence of "knots" of similar conditions. It was at first thought that the apparent complexity of the structure indicated the presence of a "stabilizing" element (such as titanium, columbium, molybdenum, or tungsten), but subsequent chemical analysis revealed a normal 18/8 alloy with no appreciable amounts of these elements. It seems most probable therefore that the cause of the very irregular structure is annealing below the austenizing temperature, as in the examples referred to in the previous paragraph. If none of the many annealings required in drawing-down from rods to fine wires had been sufficient fully to austenize the alloy, a highly complicated structure of localized variations in internal strain is to be expected. Thus the structure is apparently of type (*a*) and possibly approaching type (*b*).

After examining the last-mentioned wire a sample was obtained of an 18/8 alloy known to contain titanium, and this too was found to show pronounced irregularities. Apart from the possibility that annealing at too low a temperature was responsible for the intensity of the appearance, the presence of such a "stabilizing" element would be expected to create differences in the ferritic structure. These "stabilizers," which have a marked affinity for carbon, are included in the alloys in order to reduce the tendency to corrosion caused by the removal of chromium during the formation of carbides, more particularly at grain boundaries. Thus when any of these elements is present the small regions of the main structure near the larger precipitates of carbide will contain more chromium than is the case for the "straight" alloys. The magnetic structure may therefore be considered to be of type (*a*), in the absence of any evidence that the precipitated carbides are themselves magnetic.

No such irregularities were observed with earlier, much less sensitive apparatus, which necessitated the use of bundles of 100 wires, thus effectively masking any lack of uniformity between individual lengths. The above examples and suggestions illustrate again the value of this extremely sensitive method of magnetic testing in opening up new fields of study by all systems of investigation. In particular, X-ray analysis would be expected to disclose whether any super-lattice structure is present.

CONCLUSIONS

In the course of the study described in this paper a considerable amount of information has been obtained on the magnetic behaviour of iron–nickel–chromium wires under different conditions of cold work and heat-treatment, which it is felt should be of value in the general study of these alloys.

Certain conclusions and suggestions have been made in the various parts of the paper, and these are summarized below, where a suggestion is also made for the equilibrium diagram of the 12% nickel, 12% chromium alloy, for which, so far as is known, no such diagram has yet been published:

(1) The results of the analysis given in section (2) encourage the belief that the modified trichotometric method is capable of giving a sound picture of the basic structure of the α phase present in these alloys. Although not able of itself to fill in the details, it does, however, provide a guide to what may be expected from more detailed methods such as X-ray analysis. The structure suggested is fine fibrous layers of martensitic ferrite interspersed in the austenite.

(2) The extreme sensitivity of the apparatus, by showing up irregularities of magnetization due to variations in microstructure, opens up fields for further investigation which are not so obvious when less-refined methods of magnetic examination are employed. Study along these lines should therefore be of assistance when assessing the results of other methods of investigation.

(3) After careful study of the conclusions of Krivobok[4] and of the later tentative equilibrium for the low-carbon 18/8 alloy given by Bain and Aborn[5] (*loc. cit.*, p. 421, Fig. 11) in conjunction with the latter authors' diagrams (*loc. cit.*, p. 421, Fig. 10) showing a general lowering of the phase-change temperatures with increasing nickel relative to chromium—which change was also noted in the experiments referred to in section (6)—it is possible to form an idea of the nature of the equilibrium diagram for the low-carbon 12/12 composition.

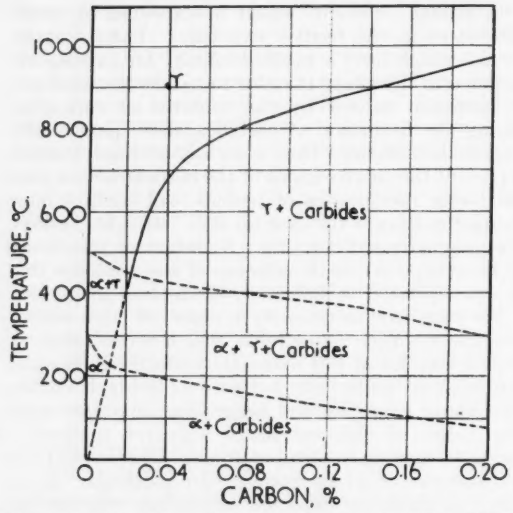

Fig. 6—Suggested equilibrium diagram for 12% nickel, 12% chromium steel, based on the diagrams of Krivobok[4] and of Bain and Aborn[5]

Figure 6 is a very tentative suggestion for such a diagram up to 0·2% of carbon, although admittedly only the range 0·08–0·12% of carbon has been covered by these experiments, no other alloys being available at the time.

APPENDIX

Several recent publications which have some bearing on the conclusions reached by the present authors have appeared since their paper was first composed.

The papers contained in the "*Symposium on Internal Stresses in Metals and Alloys*,"[35] in general show no marked departures from, but an extension of, the theoretical aspects of the subject discussed at the Conference on Strains in Solids (University of Bristol, July, 1939).

The present authors' conclusions of the structural processes involved are based largely on the report[12] of this earlier conference, and study of the papers contained in the Symposium, particularly those dealing with diffusion and precipitation, and the effects of cold work, does not suggest any radical change in these conclusions.

As a development of his original method of analysis of the magnetization curves of polycrystalline ferromagnetics, Richer[36] has proposed an elegant variation by the summation of three probability integrals, which takes account of all reversals of magnetization, both primary and secondary. There is little doubt that such a method applied to the curves analysed in the present paper would give equally good results, with some modification of the ideas put forward in section (5) on the nature of secondary reversals.

The effect of the variation in size and shape of "single-domain" particles in a non-magnetic matrix is the subject of recent papers by Professor Stonor and E. P. Wohlfarth[37] and by L. Néel,[38] which lend support to the authors' suggestion that the ferrite formation here is of small particles, some at least of which are isolated domains. In particular the high coercivity of these alloys, especially after a certain degree of heat-treatment, is explicable by these new theories. The wording of section (5), on the effect of small isolated domains is, however, in error to the extent that, if the domains are really isolated their contribution to the total magnetization with increasing external field is due to "rotations" rather than to "reversals."

A further development which has taken place is the examination of some of these wires (heat-treated and otherwise) by X-rays, acknowledgments for which are most gratefully tendered to Dr. C. Sykes, F.R.S., of the Brown-Firth Research Laboratories, Sheffield, and to Mr. H. J. Goldschmidt of the B.S.A. Group Research Centre, Sheffield (through the good offices of Dr. K. Hoselitz, of the Permanent Magnet Association Research Laboratories, Sheffield).

In each case the wire examined was an 18/8 stainless steel, drawn to a tensile strength of 150 tons/sq. in., similar to that analysed in this paper, the first sample being as-drawn, the second after heating until the remanence had fallen by some 25% and the coercivity ($_JH_c$) more than doubled, and the third when the remanence had fallen from above 5000 gauss to about 250 gauss and the coercivity had increased still further to about 250 oersted. The method of heating was by alternating current through the axis of the moving wire, so that the exact maximum temperature and time at temperature were not measurable.

The examination showed that :

(1) The lattice spacings of the austenite and ferrite were almost exactly those of γ iron and α iron respectively.

(2) Increasing heat-treatment resulted in release of internal strain in the austenite as indicated by line-sharpening in the photographs.

(3) The unheated wire contained some 50% ferrite (core of 0·003 in. dia. 60%, outer surface of 0·0005 in. thickness 40%).

(4) The heat-treatment resulted in reduction of ferrite, which was much more pronounced in the surface layer than in the core, especially in the sample having had most treatment (core 20% ferrite, surface layer 1–2% only). For the intermediate sample the corresponding figures were core 50%, outer surface 30%.

The authors are at present unable to put forward any suggestions as to the causes of this difference between core and surface, but the general results support the theory of "particle" structure of the ferrite present.

Acknowledgments

The authors wish to record their appreciation of the continued interest in their research taken by Dr. Hoselitz, of the Permanent Magnetic Association Research Laboratory, while not attributing to him any concurrence in the suggestions here put forward. Their thanks are also due to the unfailing co-operation of Messrs. Charles Hirst, wire-drawers, of Cleckheaton, for producing at their request many wires of different specifications ; and to the Directors of Messrs. Boosey and Hawkes, Ltd., for permission to publish this paper.

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Joint Committee on Metallurgical Education

Qualifications for Entrance to University Schools of Metallurgy*

THE Joint Committee on Metallurgical Education is concerned with the education of metallurgists for industry and the profession and is representative both of the industries themselves and of those actively engaged in education. Recently it has discussed at some length the education that should have been acquired by those graduating in the various University Schools of Metallurgy in this country, its particular attention having been directed to the general standard of culture attained by the graduates rather than the detailed contents of the University courses. The Committee has chosen this moment to give special attention to this subject, and to express its opinion, because of the recent issue of the White Paper on Examinations in Secondary Schools.† It believes that the Universities will shortly have to determine the conditions under which students will enter their faculties during the next few years ; and that all schools will be affected by these decisions.

The Committee appreciates that it is fitted to express an effective opinion in regard to metallurgical education only, though it believes its views on this subject may well be equally applicable to the education of students of other applied sciences, and possibly also to pure scientists. The industrial members of the Committee, themselves employers of scientists trained in different subjects, consider the opinions of the Committee to be applicable equally to graduates in any of the pure or applied sciences. Many voices have been lifted recently to deplore the specialization to which boys and girls too often are subjected during their final years at school, this state of affairs being dictated by the desire that the scholars shall perform as brilliantly as possible in those subjects which carry most weight with the University authorities when entrance is being determined. The Committee joins its voice with these others : it regrets that specialization in the schools has gone to its present lengths ; and it believes that the system produces University students narrow in outlook and interest and lacking in intellectual balance. It considers that it is for the Universities to remedy the present situation by making appropriate adjustments in their entrance requirements. Further, the Committee doubts whether the proposals in the White Paper will of themselves correct all the evils of the present system, though they could do so if the incentive were sufficiently powerful.

The Committee is fully conscious of the differences between one University and another in their entrance

* A brief note on the pamphlet published by the Joint Committee was given on p. 77 of the May issue of the *Journal*. The Recommendations are now given in full.

† Ministry of Education, Report of the Secondary School Examinations Council, 1947. London, 1947 : H.M. Stationery Office.

requirements, as well as of the difficulties that would attend an attempt to specify a precise and uniform practice. It realizes too that the schools will wish to retain some degree of freedom to act in accordance with their own circumstances, to make full use of their special facilities, and, in certain cases, to preserve old-established traditions. But it feels strongly that, on the one side, the Universities must recognize that it is possible for a man to be a specialist and at the same time to possess a broad culture ; and, on the other, that the schools can, and ought, to provide a suitably broad education without depriving a boy of adequate opportunity to develop in those subjects in which he is most interested. A boy should not, for instance, be permitted to devote his last two years at school exclusively to physics, mathematics, and chemistry, and during these years be effectively divorced from the humanities. If he goes to the University at matriculation level, it is equally inappropriate that the student's work during his first year of residence should be confined to his specialist subjects.

Since University entrance is inevitably accompanied by some measure of competition, the Committee considers that its hopes will not be achieved generally except through explicit action by the Universities themselves. It recognizes that, whereas matriculation, or its equivalent, has always been the minimum standard for entrance, it is very usual for boys to stay at school for a further two years and then take an examination of higher standard—Higher School Certificate or an Intermediate Science—usually in specialized subjects. Boys taking the latter path have been permitted to obtain an honours degree three years later, whilst those coming up with no higher qualification than matriculation spend a fourth year at the University in order to secure an honours degree. It should not be difficult to ensure that the matriculation test, or its equivalent, is broadly based ; but if a completely balanced education is to be secured it seems that further steps ought to be taken by the Universities. These aim at ensuring that a boy or girl up to what may be called the Intermediate standard should retain a close contact with subjects other than science, and should be asked to provide evidence of competence in such other subjects. To achieve this result in those who have entered at matriculation level is a problem for the Universities to solve, and the Committee believes it can safely be left with them. For school-boys seeking to enter at the Intermediate level the Committee believes that the Universities can act through the entrance examination by demanding that candidates must pass in some subjects chosen from a wide range of non-scientific options.

It may well be objected that the establishment of such an entrance examination will lower the standard set in the science subjects. This is probably true, but the Committee believes, first, that such a lowering would be but a small price to pay for a broader and more balanced culture in metallurgical graduates, and, secondly, that, on the completion of the University course, the difference in the standard attained in metallurgy would not be appreciable. Even if it were, the Committee is so convinced of the need of supplying industry and the profession with graduates well educated in the full as well as in the specialist sense that it would prefer such a result to a continuance of the present system.

It may not be fitting that the Committee should offer detailed suggestions on the entrance examination that the Universities ought to establish, and it recognizes that the Universities can hardly provide a special entrance examination for metallurgists, or even require all candidates to comply with the entrance requirements which the Committee feels should normally be applied. Nevertheless, it wishes to record its opinion that the entrance examinations appropriate for students intending to read metallurgy should recognize that candidates may enter the University either at matriculation level or at that termed the Intermediate in the preceding paragraphs. It is suggested therefore that papers corresponding generally to these two standards should be set in each subject, and that the papers in all the selected subjects should be taken at the same examination. The Committee believes that each examination should contain (1) a paper based on written English, designed to test the student's ability to express himself in writing and to understand the written word, (2) a paper in mathematics, of a standard suited to ensure that the candidate is capable of benefiting from the course he will follow at the University, (3) a paper or papers in chemistry, physics, or general science, and (4) *at least* one paper selected from a number of alternative humanistic subjects other than English. The Committee feels that a call for at least two papers in group (4) would accord more with its wishes, and this would allow a language, other than English, to be made compulsory, the selected language being either classical or modern. In these non-specialist subjects the standard set should be such as would indicate that the candidate is on the way to become a cultured member of society. Success in the papers at the lower standard in all groups would be sufficient to qualify for matriculation entrance only. Candidates wishing to enter at Intermediate standard could profitably take the higher papers in all the subjects chosen, but success at the higher standard should be compulsory in papers (1), (2) and (3), even though the lower standard were accepted in the others. It is thought that examinations framed on these lines would lead boys who sit for University entrance at the age of 17½ to 18½ to read widely in their specialist subjects during their last two years at school and, at the same time, to escape the excessive narrowness too often produced by the existing system.

It remains to refer with some emphasis to a matter not mentioned hitherto, namely, the examinations for University entrance scholarships. Under the system now prevailing, the type of paper and the competitive nature of the test have probably been the most compelling reasons for that undue and early specialization among school-boys which the Committee regrets so intensely, and the effects of which it believes to be so unfortunate. If the practice of holding separate scholarship examinations is continued, the Committee believes they must be of the same nature as those suggested for entrance, be based on a broad syllabus and include an adequate proportion of papers in subjects other than those within the candidate's special field. Furthermore, the examination should demand evidence of a proper competence in these other subjects. Unless this step is taken, the benefits deriving from a broadening of the entrance examinations will largely be nullified.

The Committee has debated the selection of students on the basis of a personal interview. This method is now widely used in certain fields, but it seems scarcely practicable to allow it to replace the written test for University purposes. Unless used with the greatest caution the selection of entrants to the Universities in this way might easily result in the exclusion of the scholar of high potentiality, who at the time he leaves school, is lacking in personality but who may well be admirably suited for research employment in later years. The Committe has no corresponding doubt as to the use of personal interviews when selecting men after graduation.

PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

ANNUAL GENERAL MEETING, 1948

THE SEVENTY-NINTH ANNUAL GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held in the Lecture Hall of the Royal Institution of Chartered Surveyors, 12, Great George Street, London, S.W.1, on Wednesday and Thursday, 5th and 6th May, 1948. The sessions on the Wednesday started at 9.45 A.M. and at 2.30 P.M., and that on the Thursday at 9.30 A.M. Dr. C. H. DESCH, F.R.S., Retiring President, was in the Chair during the first part of the proceedings, his place being afterwards taken by Sir ANDREW MCCANCE, D.Sc., F.R.S., the new President.

A BUFFET LUNCHEON was held in the Arbitration Room of the Royal Institution of Chartered Surveyors, 12, Great George Street, London, S.W.1, at 1.15 P.M., on the Wednesday, and on the Thursday a luncheon was arranged for Members and their guests at the Dorchester Hotel, Park Lane, London, W.1, at 1.15 P.M.

The minutes of the previous Meeting were taken as read and signed.

OBITUARY

The **President** (Dr. C. H. Desch, F.R.S.): I have to refer to the death of Mr. Benjamin Talbot, which occurred in December last. He was one of the best-known men in the steel industry, and, as is well known, he was instrumental in starting the basic open-hearth process in America. He had a long record at the Pencoyd works in Pennsylvania, and developed what is known as the Talbot continuous process. When he came back to this country he gave an account of that process to the Institute. He then joined the Cargo Fleet Iron Co., Ltd., with which he was associated for a long time, and also the South Durham Steel and Iron Co., Ltd. He received the Bessemer Gold Medal in 1908, and in 1928 became President of this Institute and also President of the National Federation of Iron and Steel Manufacturers.

The Members stood for a few moments in silence as a token of respect.

WELCOME TO VISITORS FROM OVERSEA

The **President** (Dr. C. H. Desch, F.R.S.): We have to welcome a number of visitors. Now that communications are a little easier than before, we are fortunately able to have with us important visitors from oversea. I shall mention those whose names I have, and I apologize in advance to any oversea visitors whose names I do not mention.

From the United States of America we have Dr. Robert Mehl, who is to give the Hatfield Memorial Lecture, and Mr. F. D. Foote, of the Carnegie-Illinois Group. From Switzerland we have an old friend, Dr. Robert Durrer, who was Chairman of the Swiss Reception Committee last year and who is one of our Honorary Vice-Presidents, and also MM. Zehnder and Hubscher, of George Fischer's, Schaffhausen. From Norway we have Dr. Goerrissen, President of the Norwegian Metallurgical Society, and Mr. G. Schjelderup. From Sweden we have Mr. Bo Tigerschiöld, a brother of the Dr. Tigerschiold who is so well known to many of us, and also Mr. Karl Bonthron, of Fagersta. From Spain we have Mr. R. de Quijano, and Mr. Luis Barreiro, who never misses a meeting of this Institute. From Belgium we have Professor Lefebvre, of Mons, and from France Mr. Rocquet, of the new research laboratory at Billancourt.

PRESENTATION OF REPORT OF COUNCIL AND STATEMENT OF ACCOUNTS FOR 1947

The **President** (Dr. C. H. Desch, F.R.S.), in presenting the Report of Council for 1947, said: There is very little that I need say about the Report, which is published in the April, 1948, issue of the *Journal*. The *Journal* in its new form has completed its first year of publication, and has certainly been well received. There have been other publications during the year, including the Symposium on the Hardenability of Steel and the Symposium on Powder Metallurgy, and we have published the first Report of meetings of the Affiliated Local Societies, the publication of which will become a regular feature of the Institute's work.

During the year we have had very close collaboration with B.I.S.R.A., and we are particularly indebted to its Director, Sir Charles Goodeve, F.R.S., for the help which he has given in negotiating the arrangements between the two bodies.

The library and information service and the translation and abstracting services have made very satisfactory progress.

In addition to the ordinary meetings, certain special meetings have been held to deal with specific subjects.

The meeting which was held in Switzerland was very successful, and we are particularly grateful to Professor Durrer for what he did for us on that occasion. Those of us who took part in that meeting know how successful it was, and how very agreeable our stay in Switzerland was made by our colleagues in that country. Our Norwegian friends have invited us to visit Norway next year. In all probability members of the Institute taking part in the visit will leave England on 25th June and return on 9th July, 1949. The Norwegian steel industry, though not on such a large scale as that in some other countries which we have visited, has particularly interesting features, and a visit to Norway has many attractions besides that of visiting steelworks.

Co-operation with other societies has been very close, especially with the Institute of Metals and the Institution of Metallurgists, which are housed in the same building as our Institute. The Institution of Metallurgists has appointed a new Registrar-Secretary, Dr. A. D. Merriman, G.C., who I think is here for the first time. There has been successful co-operation with the Affiliated Local Societies and with others abroad, reports of which will be found in the *Journal*. The Iron and Steel Engineers Group of the Institute, a recent foundation, has been particularly active. Their meetings are always very well attended, and those who attend are experts actually engaged in the engineering side of metallurgy. The papers and discussions are always of a very high standard.

Much work has been done by the Joint Committee on Metallurgical Education, and a report has been published on "Qualifications for Entrance to University Schools of Metallurgy." The scheme for National Certificates in Metallurgy has made good progress; seventeen schemes have now been approved for the Ordinary Certificate and eight for the Higher Certificate. Examinations this year will be held in at least eighteen technical colleges.

The membership of the Institute is still increasing, and later on the actual figures will be given.

I will now ask the Honorary Treasurer, Mr. Lyttelton, to present the Accounts.

The Hon. **R. G. Lyttelton** (Honorary Treasurer) presented the Statement of Accounts for 1947, as set out in the April, 1948, issue of the *Journal*, pp. 429–432. In doing so, he said: I do not wish to refer to anything at length. The Balance Sheet of the General Fund is presented in the usual form, but the Income and Expenditure Account has been made simpler, in order to show more clearly the cost of the various activities of the Institute. It sets out the various branches of expenditure. The deficit for the year was £6682, which is an anxious figure. The expenditure amounted to £34,000 odd, as against £27,000 odd last year. The chief items included salaries for the staff, at over £20,000, and superannuation fund for the staff, at about £2400. These figures represent a full year's operation of the post-war programme of development—we have enlarged our activities a great deal—and the first year's membership of the Metallurgical Societies' Joint Pension Scheme for the staff.

The income from members' subscriptions was £10,879, and from investments and other sources £1697. Companies' special subscriptions were £3884, and the Council wish to thank the Companies which subscribed. The grant from the British Iron and Steel Research Association was £16,429, which includes the cost of publishing B.I.S.R.A. papers.

The Accounts of the Trust Funds are in the usual form. The reserves of both the Andrew Carnegie Trust Fund and the Williams Prize Fund have been increased, and they are in a sound condition. The loans from both Trusts to the General Fund of the Institute have been repaid since the beginning of this year.

The Council are taking an anxious interest in the financial position. We put aside reserves during the war in order to develop after the war, and these developments are now taking place with the *Journal* and so on, but the expenses have outrun the income. The expenses of publishing, and printing in particular, have gone up to astronomical figures, and that has put our calculations out to a certain extent. The Council, and a special Committee appointed for the purpose, are looking into these matters to see where we stand, and we have had some very interesting advice from Dr. Mehl, who has been on a similar Committee in respect of the American Institute of Mining and Metallurgical Engineers, whose difficulties seem to be precisely the same as ours; in fact, their very interesting report, which we have had the privilege of seeing, might have been written by ourselves.

The **President** moved the adoption of the Report of Council and Statement of Accounts for 1947. The motion was carried unanimously.

AWARD OF THE BESSEMER GOLD MEDAL FOR 1948 TO MR. W. J. DAWSON, C.B.E.

The **President** (Dr. C. H. Desch, F.R.S.): We now come to the presentation of Medals, and the first to be presented is the Bessemer Gold Medal, which has been awarded for so many years by the Institute. This year it has been awarded to Mr. Wilfred John Dawson, in recognition of his contributions to the development of steel castings and to the production of alloy and heat-resisting steels. (*Applause.*)

Mr. Dawson has been associated all his life with Sheffield. He was one of the early pupils of Professor Arnold, and at the age of 18 obtained his Associateship at what was then the Technical School at Sheffield, which afterwards became the Applied Science Department of the University. After a short time with Messrs. Henry Bessemer and Co., Ltd., he entered the firm of Messrs. Hadfields, Ltd., with which he has ever since been associated. He did a great deal of good work when he was in charge of the steelmaking department of the Hecla Works. He was very closely associated with Sir Robert Hadfield in all the work that Sir Robert carried out, and was responsible for most of the experimental work on which the researches which were undertaken were based.

He has taken a leading part since then in co-operative research, particularly during the last war, when he was Chairman of the Technical Advisory Committee of the Ministry of Supply, a member of the Metallurgy Committee of the Advisory Council on Scientific Research and Technical Development, and a member of the Iron and Steel Technical Committee of the Ministry of Supply. He was also Chairman of the Tanks Cast Armour Committee and a member of the Tanks Wrought Armour and Aircraft Armour Committees. He has been a member of most of the important Committees dealing with research on iron and steel. He is or has been a member of the Engineering Divisional Council and the Iron and Steel Industry Committee of the British Standards Institution; Chairman of the Steel Castings Research Committee, the Corrosion Committee, and the Alloy Steels Committee, which were Joint Committees of this Institute and of the British Iron and Steel Federation, and on these bodies he has done most valuable work.

He was responsible for the introduction of one of the most important of alloy steels, and is one of the best-

known metallurgists in the steel industry. He was awarded the E. J. Fox Gold Medal of the Institute of British Foundrymen in recognition of his work as Chairman of the Steel Castings Research Committee. He is now an Honorary Vice-President of this Institute.

All those who know him well feel that he has most thoroughly deserved this honour, and I know that the award will give much pleasure to those who have been associated with him in Sheffield over so many years. As myself a member of those Research Committees which I have mentioned, I should like to refer to the courtesy and efficiency with which he has always presided over them.

The President then, amid applause, made the presentation.

Mr. **W. J. Dawson,** in reply, said : As many of you know, I am not one of those who make very long speeches, and if this award had depended upon that I am afraid that I should not have received it. My career was interrupted rather suddenly, and I had to leave my good friends on the Research Committees without any ceremony, so that I should like to greet them and to thank them very much for all the help that they gave me during the war years, when matters were urgent and hectic.

You will have gathered from the President that my career has lasted for well over half a century, and that I began my steelworks experience at the works of Henry Bessemer, the founder of the Sheffield works, and also the founder of the Medal which I have had the honour to receive today. You may be interested to know that soon after I was appointed to Bessemer's a small boy fresh from school in short trousers came to join the staff. That little boy was W. H. Hatfield. He was a very precocious little boy. I felt certain that he would make his mark, and he certainly did. The Institute owes a great debt of gratitude to him, and also to Dr. Swinden, who was my close colleague and friend.

I thank the President and the Council for the award of this Medal, which is a very rich and ample reward for what I have been able to do for the industry during the last fifty years.

THE SIR ROBERT HADFIELD MEDAL

The **President** (Dr. C. H. Desch, F.R.S.) : The Sir Robert Hadfield Medal, a more recently established honour, is awarded this year to Mr. A. Preece, in recognition of his researches on the scaling and on the overheating and burning of steel. Mr. Preece is Lecturer and Reader in Metallurgy at Leeds University. Before that he held industrial posts, and was research assistant to Principal Edwards at Swansea. He is now President of the Leeds Metallurgical Society, and as such is an Honorary Member of the Council of the Institute.

Many of us have followed with very great interest the excellent research work that Mr. Preece has done in Leeds ; he has established a reputation for original work in quite a small university department. We cannot give him on this occasion the Medal, because it is not available at the moment, and will be sent to him later, but we are very pleased to present to him the certificate which goes with it.

The President then, amid applause, made the presentation.

THE WILLIAMS PRIZE FOR 1947

The **President** (Dr. C. H. Desch, F.R.S.) : The Williams Prize for 1947 has been awarded to Mr. R. Fowler, blast-furnace superintendent with Messrs. Richard Thomas and Baldwins, Ltd., of Ebbw Vale. The award is made for a particular paper, which in this instance is the paper which Mr. Fowler contributed on " *Blowing-Out a Blast Furnace,*" which was printed in the *Journal* for April, 1947. Mr. Fowler received his early training in blast-furnace practice with Messrs. Bolckow Vaughan and Co., Ltd., and for a number of years was engaged in India in the running of blast-furnaces. When he came back to this country he joined the firm of Messrs. H. A. Brassert and Company, and then took up a position with Messrs. Richard Thomas and Baldwins, Ltd., where he is blast-furnace superintendent. During the two years that I spent with them I had occasion to find what a great expert Mr. Fowler was on all blast-furnace questions, and those metallurgists who are interested in blast-furnaces have always found his advice most helpful.

The President then, amid applause, made the presentation.

GREETINGS FROM AMERICAN INSTITUTES

The **Secretary** (Mr. K. Headlam-Morley) : I have to read a letter from the Secretary of the American Institute of Mining and Metallurgical Engineers :

" To the President and Council of The Iron and Steel Institute of England, Greetings.

The American Institute of Mining and Metallurgical Engineers desires to felicitate The Iron and Steel Institute on the occasion of its Annual Meeting, to be held in London in May, 1948. It commends the Institute for its outstanding contributions to the progress of the iron and steel industry through the dissemination of technologic and engineering information. It regards as an expression of cordial co-operation and mutual understanding the selection of Dr. R. F. Mehl, one of its valued members, to deliver the Hatfield Memorial Lecture at the 1948 Annual Meeting. It has formally delegated Dr. Mehl to bring its greetings to The Iron and Steel Institute, with best wishes for its continuing success."

The following cablegram has also been received :

" Greetings to our good friends in The Iron and Steel Institute and best wishes for a successful meeting."

WALTER S. TOWER,
President of the American
Iron and Steel Institute.

CHANGES ON THE COUNCIL

The **Secretary** (Mr. K. Headlam-Morley) : I have to report the following changes on the Council since the last General Meeting in the autumn of 1947 :

New Member of Council—Mr. T. Jolly.

New Honorary Members of Council—The following are Honorary Members of Council during their periods of office :

Sir Arthur Smout, President of the Institute of Metals, in place of Colonel P. G. J. Gueterbock, C.B., D.S.O., M.C.

Dr. C. Sykes, F.R.S., President of the Sheffield Metallurgical Association, in place of Mr. T. F. Russell.

Mr. Basil W. Doncaster, President of the Sheffield Society of Engineers and Metallurgists, in place of Mr. Ambrose Firth.

Mr. A. Hemingway Jones, who has since been succeeded by Mr. H. F. Padbury, President of the Ebbw Vale Metallurgical Society.

Mr. A. Preece, President of the Leeds Metallurgical Society.

In accordance with Bye-Law 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting, 1947, as being due to retire at the present Annual Meeting :

Vice-Presidents—Mr. J. R. Menzies-Wilson, Mr. James Mitchell, and Mr. R. Mather.

Members of Council—Mr. I. F. L. Elliot, Mr. C. R. Wheeler, Mr. E. F. Law, Dr. C. Sykes, F.R.S., and Mr. D. A. Oliver.

No other members having been nominated up to one month previous to the present Meeting, the retiring Vice-Presidents and Members of Council are now presented for re-election.

The **President** (Dr. C. H. Desch, F.R.S.) : I declare them duly re-elected.

OTHER ANNOUNCEMENTS

The **Secretary** (Mr. K. Headlam-Morley) : The Autumn General Meeting will be held in London on 10th and 11th November, 1948.

An Andrew Carnegie Travelling Scholarship has been awarded to Mr. A. W. Postlethwaite for the study of powder metallurgy in the U.S.A.

Mond Nickel Fellowships in Metallurgy for 1947 have been awarded to Mr. D. R. G. Davies, for the study of the application of statistical methods to plant metallurgical and management problems, with particular reference to the steel industry in England and the U.S.A., and to Mr. L. H. Walker, for the study of the methods of application of group industrial research, particularly in relation to the fabrication of light metals in the U.S.A.

BALLOT FOR THE ELECTION OF MEMBERS AND ASSOCIATES

Dr. L. NORTHCOTT and Mr. H. BULL, who were appointed scrutineers of the ballot, reported that the following two hundred and five candidates for membership and ninety-six candidates for associateship had been duly elected :

Members

Adamson, James Lamb (London) ; **Ameen,** Einar Louis (Surahammar, Sweden) ; **Austin,** William Wyatt, jun., Ph.D. (Birmingham, Alabama, U.S.A.) ; **Bailey,** Tom Cyril (London) ; **Baillie,** James (London) ; **Bárta,** Prof. Eng. Dr. Rudolf (Prague, Czechoslovakia) ; **Beaumont,** Patrick (Shotton, near Chester) ; **Beilby,** Robert Buxton, M.I.M.E., F.R.I.C.S. (Corby, Northants.) ; **Berger,** Ollie J., sen. (Chicago, Illinois, U.S.A.) ; **Bethel,** Richard Morgan (Ebbw Vale, Mon.) ; **Bezbora,** Nagendra Nath, B.Sc. (Met.) (Chelmsford, Essex) ; **Bhat,** Uppinangady Vaman, B.Sc.(Met.) (Benares, India) ; **Bird,** David, Assoc.Met. (Bilston, Staffs.) ; **Bishop,** Alfred Coventry Carswell (Motherwell) ; **Black,** George H. (London) ; **Blanchard,** Albert John (London) ; **Bool,** Frank Norman, A.M.I.E.E. (Rotherham) ; **Bonelle,** James (St. Briavels, Glos.); **Boyle,** James Leslie (Millom, Cumberland) ; **Brace,** Eric George (Ebbw Vale, Mon.) ; **Bull,** Stanley Ivor (Bilston, Staffs.) ; **Carrier,** Arthur William, Assoc.Met., F.I.M. (Luton) ; **Catterall,** Herbert Grey (London) ; **Clarke,** Charles Sturman (Luton) ; **Claussen,** Gerard E., Ph.D., S.M., M.E. (Baltimore, Maryland, U.S.A.); **Clements,** Thomas Edwin, B.Sc. (Corby, Northants.) ; **Colbach,** Paul (Brussels) ; **Dancy,** Terence Ernest, B.Sc., A.R.C.S. (London) ; **Darnis,** Bartolomé (Lugones, Asturias, Spain) ; **Davies,** I. B. (Port Talbot, Glam.) ; **Dearden,** John, M.Sc., A.M.I.Mech.E. (Derby) ; **Dibley,** Cornelius, A.I.M. (Thames, New Zealand) ; **Dickinson,** George Frederick (London) ; **Dingwall,** Ronald, A.M.I.E.E. (Middlesbrough) ; **Dixon,** Harold Francis (Witton, Birmingham) ; **Dixon,** Percy Alfred (Scunthorpe) ; **Dowde,** William (Bilston, Staffs.) ; **Edlund,** Lars Gustaf (Hagfors, Sweden) ; **Edmondson,** Harold Leonard, B.Sc., A.M.I.Mech.E. (Corby, Northants.) ; **Evans,** Richard Arthur Austin (Aberdare, Glam.) ; **Ewen,** Emil (Petange, Luxemburg) ; **Eyt,** Eugène (Pamiers, France) ; **Fahie,** William Cusack, M.Sc., A.M.I.E.E. (London) ; **Firth,** John Edward (Shotton, near Chester) ; **Fleming,** Herbert (Scunthorpe) ; **Fleming,** Robert Keith (Bedford) ; **Francis,** Stanley James (Shotton, near Chester) ; **Escala,** Vicente (Guipúzcoa, Spain) ; **George,** David W. (Ebbw Vale, Mon.) ; **Giaccone,** Davide (Turin, Italy) ; **Gillies,** William (Motherwell) ; **Gordon,** Ian Humphry (London) ; **Gordon,** John (Motherwell) ; **Gorrissen,** Johan, Dr.Ing. (Oslo, Norway) ; **Graham,** George Marlow (Jörpeland, Norway) ; **Greenwood,** Lawrence (Shotton, near Chester) ; **Griffiths,** Evan Edward (Ebbw Vale, Mon.) ; **Gruenfeld,** Ernst, B.Sc. (Sheffield) ; **Hamill,** Harold L. (Los Angeles, California, U.S.A.) ; **Hardy,** Frederick, A.M.I.Mech.E. (London) ; **Harper,** Henry Graham, A.I.M. (Crayford, Kent) ; **Harper,** William Lyddon, B.Sc., A.F.R.Ae.S. (Patricroft, Manchester) ; **Harvey,** Thomas Wilson (London) ; **Heijne,** Axel T. H. von (Söderfors, Sweden) ; **Hellier,** Albert Gordon (Cardiff) ; **Hewitt,** Ernest Stanley (Wednesbury) ; **Hill,** Arthur Joseph (Redcar) ; **Holdsworth,** Clement Henry (Corby, Northants) ; **Holey,** Michael Chatterton, B.Sc., A.M.I.M.E. (Kettering, Northants.) ; **Hopkin,** Graham Llewellyn, B.Sc.(Met.) (London) ; **Howat,** David Dickie, Ph.D., B.Sc., F.R.I.C., A.M.I. Chem.E. (Glasgow) ; **Hunter,** William (Workington, Cumberland) ; **Hurst,** John (London) ; **Ibbotson,** George Gilbert (Sheffield) ; **Iráizoz Oyarzun,** Faustino (Santander, Spain) ; **James,** J. A. (Ebbw Vale, Mon.) ; **Jenkins,** William David, B.Sc. (Ebbw Vale, Mon.) ; **Jepson,** Douglas, M.Sc., F.I.M. (Birmingham) ; **Jermy,** Kenneth Edward, B.A. (London) ; **Johnstone,** William, A.I.M. (Glasgow) ; **Jones,** Frederick Wilson, Ph.D., B.Sc. (Sheffield) ; **Jones,** Garnet Everard (Ebbw Vale, Mon.) ; **Jove Cima,** Pedro (Mieres, Spain) ; **Keene,** Richard Thorpe (Shotton, near Chester) ; **Kitchin,** Norman Tyson, B.Sc., A.M.Inst.C.E., A.M.I.M.E. (Brigstock, near Kettering) ; **Klein,** Elias (Pretoria, South Africa) ; **Klemantaski,** Sidney, B.Sc., A.R.C.Sc. (London) ; **Klimecki,** Wojcieck, Dipl.Ing.(Met.) (Cracow, Poland) ; **Kooistra,** Lambert A. (Alliance, Ohio, U.S.A.) ; **Krupkowski,** Prof. Aleksander, Ing.Met., D.Sc. (Cracow, Poland) ; **Larranaga,** Ramón M. (Guipúzcoa, Spain) ; **Lawrence,** John Thomas (Leighton Buzzard) ; **Leighton,** C. (Ebbw Vale, Mon.) ; **Lerici,** Carlo Maurillo, Dr.Ing. (Milan, Italy) ; **Leston,** William Archibald (Corby, Northants) ; **Lewis,** William Harry (Panteg, Mon.) ; **Lister,** Eric, B.Sc.(Hons.) (Corby, Northants.) ; **McLaren,** John McCulloch (Corby, Northants.) ; **McLean,** James Samuel (Ebbw Vale, Mon.) ; **McMaster,** James Gordon, B.Sc. (Sydney, Australia) ; **Macmillan,** John Graham (Corby, Northants.) ; **Magyar,** Stephen (Gerlafingen, Switzerland) ; **Mahin,** William Edward, B.S., M.S. (Chicago, Illinois, U.S.A.) ; **Marinček,** Borut, Dr.Ing. (Zürich, Switzerland) ; **Marler,** Clive William, F.C.S. (Ipswich) ; **Marsden,** Joseph Gerald (Redcar) ; **Marston,** Albert (Shotton, near Chester) ; **Maynard,** Stanley Payne (Bedford) ; **Mazzoleni,** Francesco (Naples, Italy) ; **Mellor,** Arthur, F.R.I.C.S. (Brigstock, near Kettering, Northants.) ; **Miller,** Alexander Augustus (London) ; **Miller,** Thomas William, M.A., B.Sc. (Letchworth, Herts.) ; **Misra,** Monojmohon, B.Sc. (Enfield, Middlesex) ; **Monteiro,** Julio De Moura (Rio de Janeiro, Brazil) ; **Monvoisin,** Jean (Billancourt, Seine, France) ;

Mukherjee, Sontosh Kumer, M.Sc. (Muradnagar, India); **Muller,** Albert, Ph.D.(Met.) (Murray Hill, N.J., U.S.A.); **Myatt,** Ronald Tom (Bilston, Staffs.); **Naim,** Syed Muhammad, B.Sc.(Met.) (Swansea); **Nash,** William F., jun., Ph.D., M.Sc. (Alhambra, California, U.S.A.); **Navarro,** José (Madrid, Spain); **Neves,** Frederick (Nottingham); **Newsbrander,** Stanley M. (Weirton, Va., U.S.A.); **Newton,** Charles Harold, A.I.M. (Tipton, Staffs.); **Nix,** Foster C. (Philadelphia, Pa., U.S.A.); **Norvall,** Francis John (Birmingham); **Nutbrown,** James (Sheffield); **Oller,** Pedro (Madrid, Spain); **Old,** Theodore F. (Middletown, Ohio, U.S.A.); **Owe,** Aage W. (Oslo, Norway); **Parish,** Herbert Thomas (London); **Parker,** William Holme Cameron, L.I.M. (Glasgow); **Paues,** Nils Christian (Hällefors, Sweden); **Penry,** Benjamin W. (Ebbw Vale); **Phillips,** William Evan Havard (Ebbw Vale); **Pierre,** Ugo De La (Aosta, Italy); **Powell,** Raymond C., B.Sc. (Ebbw Vale, Mon.); **Reddi,** Devan Venkata, B.Sc.(Met.), A.I.M., B.E.M. (Ishapore, West Bengal, India); **Ricci,** Cornelio (Aosta, Italy); **Richards,** Geoffrey (Bilston, Staffs.); **Rizk Bey,** *His Excellency* Ahmed Mohamed (London); **Roy,** Leslie V. (Redhill, Surrey); **Roberts,** Archibald Lewis (Shrewsbury); **Robson,** John Edward, M.C. (London); **Salis,** Manuel (Madrid, Spain); **Savage,** John, B.Sc.(Hons.), A.Inst.P. (London); **Shaw,** Thomas Edward (Scunthorpe); **Sheward,** George Edward (Bilston, Staffs.); **Shone,** Robert Minshull, M.Eng., M.A. (London); **Smith,** Bernard Senior, M.Met.(Hons.) (London); **Smith-Christensen,** Thorstein, B.Sc. (Oslo, Norway); **Sneddon,** Andrew (Ebbw Vale, Mon.); **Sneddon,** George Thomas (Motherwell); **Snow,** Henry, M.A.(Hons.) (Sheffield); **Somerville,** William (Motherwell); **Sommerville,** David (Motherwell); **Speakman,** John Edward Davan, B.Sc.(Eng.), A.M.I.E.E. (Sheffield); **Spooner,** William (Minas Gerais, Brazil); **Stafford,** John Ward Slingsby, Assoc.Met., A.I.M. (Sheffield); **Steele,** James Henry (Ebbw Vale, Mon.); **Steiner,** Dora R., Dipl.Ing., Dr.Ing. (London); **Stoker,** Pieter, B.Sc.(Eng.), Dipl.Ing. (Pretoria, South Africa); **Stringer,** John, B.A.(Hons.) (London); **Taylor,** Benjamin Melville (Workington, Cumberland); **Taylor,** Harry, B.Sc.(Met.) (Millom, Cumberland); **Taylor,** Harry Charles, B.Sc. (Hons.), A.M.I.C.E. (Corby, Northants.); **Taylor,** J. Russell, B.Sc., M.I.Mech.E., M.I.E.E. (Bedford); **Thomas,** Constant (Brussels); **Thomas,** Jeffrey James (Ebbw Vale, Mon.); **Thomas,** Thomas (Ebbw Vale, Mon.); **Thomson,** John, A.I.M. (Motherwell); **Tigerschiöld,** Bo Magnus (Degersfors, Sweden); **Tingle,** Arthur Edgar (Cleveland, Transvaal, South Africa); **Turner,** Sidney (Port Talbot, Glam.); **Urbano,** Luis (Madrid, Spain); **Van Der Ben,** Charles Robert (Ashton-under-Lyne, Lancs.); **Vedanth,** Thatnapallo Chakravarthy (Jaipur, Rajputana, India); **Waite,** Ronald Thomas (Consett, Co. Durham); **Walburn,** Douglas Rhind (London); **Waldemar,** Jönsson O. J. (Filipstad, Sweden); **Wall,** George, B.Sc.(Hons.) (Corby, Northants.); **Watkins,** Herbert Edward, A.M.I.Mech.E. (Newcastle-upon-Tyne); **White,** Graham John Arthur (Workington, Cumberland); **White,** Reginald Clifford, B.Sc. (Swansea); **Whiteley,** S. (Rishworth, near Halifax); **Williams,** Edward Jeffrey (Shotton, near Chester); **Williams,** Henry T. (Ebbw Vale, Mon.); **Williams,** Idris, B.Sc. (Ebbw Vale, Mon.); **Williams,** John Thomas Evan, B.Sc.(Hons.) (Corby, Northants); **Williams,** J. R. (Port Talbot, Glam.); **Williams,** Sydney (Ebbw Vale, Mon.); **Williams,** W. B. (Ebbw Vale, Mon.); **Williams,** William Evan (Ebbw Vale, Mon.); **Wilson,** Charles Henry (Nottingham); **Wohlfahrt,** Sixten (Domnarvet, Sweden); **Wood,** Charles Guthrie (Paisley); **Woodward,** Arthur (Ebbw Vale, Mon.); **Workman,** Rupert Cecil (Pontardawe, near Swansea); **Worthington,** John Edward, B.Sc. (Sheffield); **Wright,** Philip, M.C., B.Sc. (Workington, Cumberland); **Wright,** William Beveridge (Glasgow); **Yendoll,** James N. (Ebbw Vale, Mon.); **Young,** Eric Vincent (Neath Glam.); **Zazzaroni,** Aldo (Aosta, Italy); **Zoja,** Dr Raffaello (Aosta, Italy).

Associates

Adams, Ean Travis (Sheffield); **Ainsbury,** Desmond William, A.M.Inst.B.E. (Corby, Northants.); **Akinci,** Abdulmecit (Birmingham); **Arthur,** Patrick Terence, B.Sc.(Hons.Met.) (Glasgow); **Bale,** Ernest Samuel (London); **Barker,** Alfred Stanley (Scunthorpe); **Barton,** Ralph (Birmingham); **Bastow,** Clifford (Leeds); **Batten,** Desmond James (Ebbw Vale, Mon.); **Bell,** Raymond John (Ebbw Vale, Mon.); **Bhattacharya,** Sarnendu, B.Sc.(Met.) (Manchester); **Blade,** John Clements, B.Sc. (Hons.) (London); **Brace,** Arthur William, L.I.M. (Bristol); **Brooker,** Derek William (Letchworth, Herts.); **Carden,** David George Randall (Corby, Northants.); **Carlos de Oliveira,** Antônio (Estado do Rio, Brazil); **Cartwright,** Harry (Wolverhampton); **Chuang,** Yu Chih, B.Sc. (Liverpool); **Condè,** John Frederick George, B.Sc. (Hons.) (Birmingham); **Davies,** Graham Hill (Swansea); **De Bie,** Rafael (London); **Devine,** Frank (Leeds); **Dick,** *Lieut.* Raymond Henry (Washington, D.C., U.S.A.); **Evans,** Windsor (Swansea); **Firth,** Arthur (Corby Northants.); **Firth,** Robert Waring, B.Sc.(Met.) (Newcastle-upon-Tyne); **Fletcher,** Ronald Gordon, B.Sc. (Ebbw Vale, Mon.); **Glenny,** Robert Joseph, B.Sc. (Chem.), B.Sc.(Met.) (Whetstone, near Leicester); **Griffiths,** Vernon (Swansea); **Grigg,** Michael Andrew (Weybridge); **Guenot,** Robert (Sheffield); **Habershon,** Percy (Sheffield); **Hall,** Harry Coolerammar (Stockton-on-Tees); **Hardie,** William (Motherwell); **Henrys,** Frank (Stockport); **Heptonstall,** Peter (Leeds); **Hill,** Paul E. (Wolverhampton); **Homer,** Frank (Walsall); **Ireland,** R. L. (Swansea); **Jefford,** Godfrey (Swansea); **Jenkins,** John (Swansea); **Jones,** Herbert Dennis (Newcastle-upon-Tyne); **Jones,** Kenneth (Ebbw Vale, Mon.); **Jones,** Melvyn (Ebbw Vale, Mon.); **Jones,** William John (Swansea); **Knight,** James Richard, B.Sc.(Eng.)(Met.)(Hons.), A.I.M. (London); **Kulkarni,** Anant Vishnu (Benares, India); **Law,** Geoffrey Thomas (Corby, Northants.); **Lewis,** F. V. (Ebbw Vale, Mon.); **Leyshon,** Humphrey James, B.Sc.(Hons.Met.) (Bilston, Staffs.); **Lindberg,** Nils Gunnar Emanuel (Stockholm, Sweden); **Lyne,** William C., B.Sc.(Hons.) (Sault Ste. Marie, Ontario, Canada); **McKnight,** Ian Bertram (Leeds); **Mason,** John (Walsall); **Matthews,** Eric T. (Ebbw Vale, Mon.); **Minney,** Arthur Joseph (Corby, Northants.); **Morgan,** Clifford Clive, L.I.M. (Penistone, near Sheffield); **Morgan,** William Robert (Swansea); **Mullick,** Niharendu (Burnpur, India); **Mykura,** Helmut, B.Sc.(Hons.) (London); **Newkirk,** John Burt, B.Met.E., M.S.(Met.) (Pittsburg, Pa., U.S.A.); **Nicholls,** Royston Augustus (Corby, Northants.); **Olds,** Bernard F. (Cambridge); **Otte,** Henry Martin (Birmingham); **Over,** Colin (Redcar); **Penny,** Kenneth (Ebbw Vale, Mon.); **Phillips,** Victor Arthur, B.Sc., A.R.S.M., L.I.M. (New Haven, Conn., U.S.A.); **Powell,** John Robert, B.Sc. (Coventry); **Proffitt,** Henry Joseph (Slough, Bucks.); **Pugh,** Glyn (Ebbw Vale, Mon.); **Purnell,** Alan John (Cardiff); **Richards,** John Rees Morgan (Swansea); **Shadbolt,** Ronald William (Corby, Northants.); **Shaw,** John Arthur (Leeds); **Slattery,** Gerard, B.Sc. (Swansea); **Smith,** Ronald Alfred, B.Sc. (Hons.Met.) (Birmingham); **Srawley,** John Ewart (Birmingham); **Staves,** Roy Pearce (Wolverhampton); **Stroud,** William Derrick (Ebbw Vale, Mon.); **Tait,** Donald Blakie, B.Sc.(Eng.) (London); **Thomas,** David James Dane, B.Sc. (Ebbw Vale, Mon.); **Thomas,** Ithel Orfryn Vivian (Swansea); **Thomas,** William Kenneth

Leslie (Swansea); **Thompson,** Ernest Lewis (Scunthorpe); **Tulloch,** Archibald (Corby, Northants.); **Turnbull,** George Alexander, B.Sc. (Kinlochleven, Argyll); **Tyldesley,** W. R. (Manchester); **Verney,** Leslie Reginald (Swansea); **Vest,** E. T. (Ebbw Vale, Mon.); **Whittaker,** Roy (Sheffield); **Willans,** Ronald Robert (Liverpool); **Williams,** John Randall (Wolverhampton); **Woodhouse,** John T. (Leeds); **Woodward,** Raymond (Ebbw Vale, Mon.); **Worn,** David Kenneth, B.Sc.(Hons.) (Wembley, Middlesex); **Young,** Li-Chow, M.Sc. (Birmingham).

The **Secretary** announced that the total membership of the Institute was now 4701.

INDUCTION OF THE PRESIDENT-ELECT, SIR ANDREW McCANCE, D.Sc., F.R.S.

Dr. **C. H. Desch,** F.R.S. (Retiring President): My term of office has now expired, and I have to induct a new President into the Chair. Sir Andrew McCance is, I suppose, known to everybody in this room. He is now Deputy Chairman and Joint Managing Director of the great firm of Messrs. Colvilles, Ltd. He is from the neighbourhood of Glasgow himself, and has always been associated with the industry of that important metallurgical district. He studied in London at the Royal School of Mines, and then entered the works of Messrs. William Beardmore and Co., Ltd. It was there that I first met him.

We have in the steel industry many distinguished industrialists, and we have on the academic side many distinguished research workers, but the combination of successful business manager, head of a great firm, and distinguished scientific investigator is rare. That combination we find in Sir Andrew McCance, who has made a great reputation in both fields, as a very capable business leader and also as an investigator on the scientific side of metallurgy. What is still more remarkable is that he has been able, even in later years, to combine those two activities; while carrying on the direction of a great business, sharing that with Sir John Craig, he has found it possible to carry on research work of a really abstruse kind. Certain work which he has been doing, which has not been published yet, but which I hope will be, will rank very high in the research records of this industry.

His first paper was contributed to this Institute when he was only 24. It was entitled "*A Contribution to the Theory of Hardening.*" I remember that paper very well, and the excellent scientific ideas which were put forward in it, which stimulated a great deal of later work. He took the degree of Doctor of Science of London University, and later became Managing Director of the Clyde Alloy Steel Co., Ltd. He also acted as adviser to Messrs. David Colville and Sons, joining the Board in 1930. Since then he has always been associated with the great firm of Colvilles, and has taken a leading part in every development of that Company. He is also a Director of the Steel Company of Scotland, Ltd., the Lanarkshire Steel Co., Ltd., Messrs. Smith and McLean, Ltd., and Messrs. Bruntons (Musselburgh), Ltd.

He became a Fellow of the Royal Society in 1943, and was the first Chairman of the British Iron and Steel Research Association. That Association owes a very great deal to his leadership in its early, formative years. In 1914 he became a Member of this Institute; he became a Member of Council in 1932 and a Vice-President in 1941. In 1940 he was awarded the Bessemer Gold Medal. The honour of knighthood was conferred on him by His Majesty the King in June, 1947.

He is the author of many technical papers contributed to our *Journal* and to the Faraday Society, and he has been particularly active in the application of the principles of physical chemistry to the manufacturing processes of steel.

It gives me very great pleasure to know that Sir Andrew will now become President of this Institute. He is held in the very highest respect by all our members, and I feel sure that during his period of office he will add new lustre to the name of the Institute. (*Applause.*)

Dr. Desch then left the Chair, which was taken, amid applause, by the incoming President, Sir Andrew McCance, D.Sc., F.R.S.

VOTE OF THANKS TO THE RETIRING PRESIDENT

The **President** (Sir Andrew McCance, F.R.S.): My first duty is a very pleasant one. It is to ask the members to express their thanks to Dr. Desch, the Retiring President, for all his services to the Institute and for all that he has done to make the meetings so great a success during his term of office. That term of office has been notable for two distinctions to which I think that I should draw attention. In his first year of office, Dr. Desch was appointed a Foreign Member of the French Academy of Science, which I can assure you is a very exceptional distinction. At the beginning of last year, he went to America to receive from the American Institute of Mining and Metallurgical Engineers their Honorary Membership, which is the highest honour which it is in their power to bestow.

All of us have a great admiration and respect for Dr. Desch's scientific attainments, and I feel that this Institute is proud that that same feeling should be shared by the peoples of other countries. It is with great pleasure, therefore, that I propose that the thanks of this Institute be conveyed to Dr. Desch for his services as President. (*Applause.*)

Sir **Peter B. Brown**: It gives me the very greatest pleasure to second this vote of thanks to our good friend Dr. Desch. He is too well known to you all to require any description of his virtues from me, and all that I can say is that during my very long association with the Institute I have never known a President who has devoted so much time, energy, ability, tact, and all the other virtues that are required for this office to its service. He has been fortunate in living near London, where most of the work has been carried out, and has been in constant touch with headquarters.

He has also been blessed in having the help of his very charming wife, who has looked after him and brought him up to scratch from time to time, and in thanking him we ought not to forget her. We shall all want to thank him for his wonderful work during his term of office as our President. (*Applause.*)

The vote of thanks was carried unanimously, with acclamation.

Dr. **C. H. Desch,** F.R.S.: I should like to thank Sir Andrew McCance and Sir Peter Brown, on behalf of my wife and myself, for their very kind words. My relations with the members of the iron and steel industry, and particularly with the members of this Institute, have always been most friendly, and I count myself very fortunate in having been associated with the industry. It is a very progressive one, and I hope that it will still be able to show that degree of independence which has been characteristic of it for many years. (*Applause.*)

PRESENTATION OF THE PRESIDENTIAL ADDRESS

The **President** (Sir Andrew McCance, F.R.S.) then delivered his Presidential Address. The text of the Address will be found on pp. 1–10 of the May, 1948, issue of the *Journal*.

Vote of Thanks to the President for his Address

Mr. **T. M. Service** (Messrs. Wm. Beardmore and Co., Ltd.): It gives me great pleasure to move a vote of thanks to the President for the wonderful Address which he has given us. He has reviewed the steel trade almost from its inception. The latter part of his Address has given us much food for thought, because it has covered many of the items on which we are all seeking enlightenment. We have not solved all the problems of steel furnaces yet, but Sir Andrew has given us some thoughts that will help us in the solution of these problems, and our heartiest thanks are due to him.

Mr. **E. W. Colbeck** (I.C.I., Ltd.): I have much pleasure in seconding the motion. We have listened to a very stimulating Address, and we shall go back to our plants and think over the points that the President has raised. Such Addresses as these are of the greatest value to our industry, because they stimulate our thoughts, and perhaps even hurt some of us; and that is what wants doing.

The vote of thanks was carried unanimously, with acclamation, and was briefly acknowledged by the President.

PRESENTATION OF PAPERS

The following papers were presented and discussed:

Wednesday, 5th May

Morning Session

"Construction and Repair of Open-Hearth Furnaces," by D. C. Muir.

"The Design of Open-Hearth Gas Ports," by M. P. Newby.

"Installation and Use of Instruments on Open-Hearth Melting," by R. C. Baker.

(*Joint Discussion*)

Afternoon Session

"The Production of Nodular Graphite Structures in Cast Irons," by H. Morrogh and W. J. Williams.

"The Carbides in Iron–Carbon–Silicon Alloys and Cast Irons," by D. Marles.

(*Joint Discussion*)

"Abnormal Creep in Carbon Steels," by J. Glen.

"The Creep Properties of Molybdenum, Chromium–Molybdenum, and Molybdenum–Vanadium Steels," by J. Glen.

(*Joint Discussion*)

Thursday, 6th May

Morning Session

"A Micro-Examination of Eight Steels for the Inclusions Sub-Committee," by J. H. Whiteley.

"The Study of Segregations and Inclusions in Steel by Micro-Radiography," by W. Betteridge and R. S. Sharpe.

"Some Thermodynamical Aspects of the Formation of Inclusions in Mild-Steel Weld Metal," by E. C. Rollason and E. Bishop.

(*Joint Discussion*)

"A Comparison of Moulds of Standard Composition and of Approximately Ingot Mould Sub-Committee Composition," by W. L. Kerlie.

"Mould-Weight/Ingot-Weight Ratio and its Relation to Mould Consumption," by N. H. Bacon.

"Formation of 'Double Skin' or 'Curtaining' on Top-Poured Mild-Steel Ingots," by P. Walker.

(*Joint Discussion*)

On the motion of the President, a vote of thanks was accorded by acclamation to the authors of the papers presented at the Meeting.

The discussions on these papers will be printed in a later issue of the Journal.

THIRD HATFIELD MEMORIAL LECTURE

Professor Robert F. Mehl, of the Carnegie Institute of Technology, Pittsburgh, Pa., U.S.A., presented the Third Hatfield Memorial Lecture, on "The Decomposition of Austenite by Nucleation and Growth Processes," on 5th May, 1948, at 8.30 P.M., at the Royal Institution of Chartered Surveyors, Great George Street, London, S.W.1. The text of the Lecture will be found on pp. 163–174 of this issue of the *Journal*.

MEMBERS' LUNCHEON

A Luncheon was held at the Dorchester Hotel, Park Lane, London, W.1, on Thursday, 6th May, 1948. Sir Andrew McCance, F.R.S., President of the Institute, occupied the Chair, and nearly six hundred members and guests were present, the guests including His Excellency M. L. W. Douglas (American Ambassador), His Excellency M. René Massigli, K.B.E. (French Ambassador), His Excellency M. A. J. Clasen (Luxembourg Minister; Hon. Member), Sir Oliver Franks, K.C.B., C.B.E. (Ambassador-Designate to the United States of America), The Rt. Hon. Lord Clydesmuir, P.C., G.C.I.E., Lt.-Col. Sir John Greenly, K.C.M.G., C.B.E. (Hon. Vice-President), Mr. Leif Egeland (High Commissioner for the Union of South Africa), Mr. V. K. Krishna Menon (High Commissioner for India), His Excellency Habib Ibrahim Rahimtoola (High Commissioner for Pakistan), Admiral Sir John H. G. Cunningham, G.C.B., M.V.O. (First Sea Lord and Chief of Naval Staff), Lt.-Gen. G. W. R. Templer, C.B., C.M.G., D.S.O., O.B.E. (Vice-Chief of the Imperial General Staff), Sir Charles Darwin, K.B.E., F.R.S. (Director, National Physical Laboratory), Mr. Ellis Hunter (President, British Iron and Steel Federation), Sir John Duncanson (Commercial and Technical Director, British Iron and Steel Federation; Hon. Member of Council), Mr. G. H. Latham (President, British Iron and Steel Research Association; Vice-President); Sir Charles Goodeve, O.B.E., F.R.S. (Director, British Iron and Steel Research Association; Hon. Member of Council), Sir Archibald Forbes (Chairman, Iron and Steel Board), Professor R. F. Mehl (Third Hatfield Memorial Lecturer), the Presidents and Secretaries of kindred Institutions, and a number of distinguished visitors from the Dominions and foreign countries.

The loyal toasts having been honoured, Sir **Oliver S. Franks**, K.C.B., C.B.E., Ambassador-Designate to the United States of America, proposed the toast of:

"*The Iron and Steel Institute*
and
the Iron and Steel Industry"

He said : It is a very great pleasure to me to propose this toast. Whenever I come to a meeting of iron and steel people I feel that I am among familiar friends. That is not always so. I remember that eleven years ago, at about this time of the year, I was waiting rather apprehensively—as I was two minutes ago—to give an inaugural lecture, and the gentleman in the chair, the Chancellor of a famous northern university, got up and said that the chair which I occupied was a famous one ; it had been filled for something like five centuries by Scotsmen ; it was true that once in the seventeenth century they had had an Irishman, and it was even true that once in the nineteenth century they had had a Welshman ; but never until that day had they had an Englishman. (*Laughter.*) After that, I had to give my inaugural lecture !

It is much easier to talk to the iron and steel industry, because, after all, I have known it for many years ; in fact, my knowledge of the industry goes back to the winter of 1912, when I was sent to the North of England because it was thought that my health was not good. I had a grandfather who built bridges, a Quaker who lived in Darlington, called Joseph Shewell, and he used to take me to a place called Normanby and let me see the pig iron being run out of the furnaces into the sand moulds. That is my first recollection of the iron and steel industry. My second is of a Christmas morning in 1912, when I was allowed to escape from going to a Quaker meeting in order to see the main girders of a new bridge over the railway that brought the ironstone down from the Cleveland moors being swung into place, at a time when there was no traffic.

When I think about the iron and steel industry, however, my thoughts really go back to the Ministry of Supply. There we knew the truth. (*Laughter.*) There were those who said that the sinews of war were money, and there were those who remembered Machiavelli and who said that men were the sinews of war ; we knew better. We knew that steel was the sinews of war ; and for all the years from 1939 to 1945 I had as much as anyone, who was not a member of the industry, to do with it. I had to ask members of the industry, on both sides of the industry, to do a great many things which they did not want to do at all, but I never asked for anything, for which I could give a good reason, which was not accepted and done, and done faster than the promise. (*Cheers.*) That is why I am always pleased when good fortune brings me once again to the steel industry.

In the last two years, when I have not had anything to do with government, except for casual forays to Paris or across the seas, I have watched with interest (because of the war years) and with pride (because of my friendships) the astonishing record of production which this industry has put up. (*Cheers.*) I realize that figures such as those which have been achieved do not come automatically or mechanically, and that shortages of all kinds have been encountered, contended with, and overcome, in order that the production figures month by month should be what they have been.

But I must not go on talking about the industry ; I must come to the Institute. The Institute does many things, but perhaps it chiefly exists to publish technical papers, to encourage their discussion, to form groups for the discussion of technical subjects, and to provide for the full and free discussion of the technical problems of that group of industries which we loosely call the iron and steel industry by those who are interested in it and who have a career to follow in it.

There are one or two things which I should like to say about such an Institute. The first is that it is obviously—and I know has been so in the experience of those concerned with it—a very valuable means of technical education. I think that it is worth remembering that one of the queer things about Great Britain is that for a great many years, perhaps a hundred and fifty, we have had a great many fresh and original ideas in what is called fundamental research—almost more than our fair share of them—but we have not always been sufficiently interested to develop those ideas and see how they could be fitted in to improve our commercial and our industrial practices. The part of an Institute such as this, as I conceive it, is to take hold where in the universities they leave off with their fundamental ideas and to carry on a research not less rigid in its standards, not less objective, conforming equally to the canons of scientific method, to find out, within the sphere of the ferrous metals, what can be discovered by the inquisitive intellect of man.

That is a big thing to do in itself, and it is a big thing for the industry ; but there is another part of it which we may also look at, just in passing. I doubt whether any democracy really lives by bread alone, simply by the accumulation of material prosperity. I think that it takes more than that today, when we who believe in a constitutional democracy have to have faith that that is a good way of living and one which we want to hand on to our children and to our children's children.

You may think it queer that a technical Institute should be an important organ of democracy, but I believe that it is, and for this reason. Where you have men meeting together to discuss the truth, as they see it, about one of the concrete subjects of natural science, there you have a disciplined obedience to a standard of life which is something which owes nothing to authoritarian regimes or to rules imposed by man. It is a very old-fashioned thing ; it is something which is called the pursuit of truth. That is rather a queer thing to talk about at lunch-time, perhaps, in the context of a technical Institute ; but I venture to say that the pursuit by the curious mind of the objective truth, unfettered by any political, social, or religious discrimination, is one of the things by which a democracy lives. (*Applause.*) You, in the iron and steel industry, through your Institute, play a part not only in advancing the knowledge of the ferrous metals, of their processing and their products, but also in adding your brick to the edifice of democratic procedure which we have in this country, and which we intend to keep. (*Applause.*)

The research which we pursue has not merely as its end the improvement of our knowledge and the making of us better citizens of a country like this, however ; it has a practical purpose also, which does not detract from these other purposes, but crowns them, and that is, in its application to the iron and steel industries, the improvement of their processes and the improvement of the products of those industries. Now, on that I would say only one thing. This country is now some two and a half years gone in its post-war adjustment. It has not finished that adjustment ; there is a lot more to come. We are still—and not only we, but the other countries of the world with us—rocked in the heavy after-swell of the greatest war that the world has known. It is unreasonable to think that that swell will die down very quickly. It is unreasonable to think that we in this country should be sailing away on a flat ocean of prosperity next week or next month or next year. But it is reasonable to think that if we use our brains and if we use our technical Institutes, if we find out fresh knowledge and find out how to apply it, how to develop the plant, how to refine the products, how to arrive at a better quality and price, and pass them on to our

consumers, we shall complete our adjustment in triumph, and the industries of this country will once more make us secure and prosperous, as everyone here, both British and our friends from overseas, hope to see us in the years to come.

All this is part of what a technical Institute is for. It is to find out the truth about its subject-matter, to practise its members in the free pursuit of objective truth with disciplined minds, and to improve the efficiency of the industry with which it is connected, so that it can play its full part in the reconstitution of our own country and our own industry and all that to which we attach importance. It is with that in mind that I give you the toast of "*The Iron and Steel Institute and the Iron and Steel Industry.*" (*Applause.*)

The President (Sir **Andrew McCance,** D.Sc., F.R.S.) said in reply : In thanking Sir Oliver Franks, on behalf of the members of the Institute, for the admirable way in which he has proposed this toast, I should also like to convey to him our warm appreciation and congratulations on his appointment as His Majesty's Ambassador to the United States. (*Applause.*) That appointment continues the long series of distinguished men who have occupied that position, and those of us who have had the privilege of association with Sir Oliver in some of his former activities know that his outstanding qualities will ensure the certainty of his success in handling the many difficult responsibilities that lie ahead. (*Applause.*) He takes with him to his new sphere of service our most cordial good wishes.

Sir Oliver has dealt with some of the broad issues that unite The Iron and Steel Institute with the industry which it serves. There are many kindred Institutes, and they have grown amazingly during the past fifty years. They supply a very definite human need, for the desire to formulate opinions and to have them discussed is one of the strong characteristics implanted in the human race. When you unite such desires with our gregarious and social instincts, it is not difficult to understand why technical societies have flourished so well.

Their progress, I suggest, has considerable significance to us today. Let us bear in mind that the older societies really came into being in a rebellion against control. Societies like the Royal Society and the French Academy of Science were the first fruits of our efforts, about three centuries ago, to deny ecclesiastical control in the realm of experimental science. Men did not want human matter, however armed with powerful authority, to tell them what the results of their experiments ought to be ; they preferred that dead matter, by its reactions to their tests, should speak for itself. The success of that point of view really laid the foundation for our progress today.

Later, in the industrial era which followed, the men who applied scientific knowledge to the benefit of industry and the national economy in those days also felt the need for societies where they too could discuss among themselves the practical experience and the skill which they were fast acquiring ; and so, in and around that time, there came into being many of the kindred Institutions whose Presidents we are very glad to have with us as our guests today.

Our own Institute came into being somewhat later, in 1869 ; but that, perhaps, is not to be wondered at when we remember that the steelmaking processes associated with the names of Siemens and Bessemer—by which the bulk of the world's steel is still made today—were not brought out until 1856, and were not a practical success until some ten years later. I think, indeed, that there can be few instances where the formation of a technical society followed so soon after the creation of the industry which it was designed to serve.

That it has served it well, as Sir Oliver has said, can be admitted by everyone here. There can be few matters of importance concerning iron and steel that have not found their first expression in the pages of our *Journal.* These are the first volumes to which we turn when we want any information, scientific or industrial, concerning the industry in which we are engaged. They are the means by which the personnel in the industry keep abreast of technical developments in iron and steel throughout the world. Equally, in the *Journal* our members have made their own original contributions to scientific thought and practical advancement.

Primarily, they have done these things because of their keen interest in their work, and because they were keenly interested in the subject of technical metallurgy. At the same time they were widening their experience and fitting themselves all the time for positions of responsibility and authority. The younger men were aware that sooner or later they would be called on to occupy positions of leadership and to apply the experience and skill which they had acquired. Whatever the future held for them they were confident in the knowledge of their own ability, and were also aware that the operating companies in the iron and steel industry were always seeking for men with skill and energy and were ever ready to offer them the responsibilities for which they craved.

I can speak from my own experience in confirmation of what I am saying. I recall at the beginning of my industrial career the men who were active in our discussions and who took part in the work of this Institute, and who in those days shared with me a happy freedom from responsibility. When I look around I see many of them here today, I am glad to say. When I think of the burdens they now carry, I can imagine that they look back with nostalgic regret to the simplicity of those days when cares were carried lightly.

No success, however, comes to anyone without the determination to succeed and without the freedom to choose his own path to success. We have always enjoyed that freedom of choice in the past ; are we going to enjoy that freedom in the future ? That is a question which we must ask ourselves in these times of change. We cannot but be aware of the ever-increasing power of the State in industrial matters, and in fact in all matters that concern our daily life, for it is being planned that the State shall acquire such power. It is being planned that one by one the control of the industries of this country shall pass over to the State and, as we know from the price of coal, some of them have already passed over. (*Laughter.*) It may be that in some industries there will soon be only one employer.

That raises important issues. What is going to be the position of any member of our technical Institutions who has equipped himself by hard work with experience and scientific knowledge for a position of responsibility, if he has the misfortune in course of time to incur the displeasure of his one employer ? To what can he turn if he wishes to continue to exercise his profession ? Or, perhaps, having attained a position of responsibility and importance in one of these new organizations, what will his feelings be if he finds that the very highest positions are reserved to others, for reasons of State policy or political service ? (*Applause.*) These are questions which we must ask ourselves. Sooner or later an answer will be required if the system of State supremacy progresses. After all, it is not a new system. There are, I believe, countries where it is highly regarded (*Laughter*), particularly by those who hold the reins of power in their hands ; but I cannot say, looking at them, that so far

that system has shown any noteworthy indication of consideration for others.

I am reminded of the story of a group of men who were studying the protective instinct in animals. The subject of their experiment was a chimpanzee with a baby, and for the experiment a heater was introduced into the floor of its cage. At the beginning of the experiment a small amount of heat was turned on. The chimpanzee looked round apprehensively, and lifted the baby on to her knee. A little more heat was turned on, and again she looked round apprehensively and clasped the baby to her shoulder. Further heat was turned on until the floor became really warm. The chimpanzee looked round suspiciously. Then she put the baby on the floor and stood on it. (*Laughter.*) That story seems to me to illustrate one of the fundamental principles of State planning. (*Laughter.*) No matter what happens, the State always comes out on top.

How very different are the principles on which technical Institutions like our own are founded! They can live only in an atmosphere where the freest interchange of ideas and opinions is possible. Whatever happens in the future, and whatever comes out of this fashion in our age for social progress, let us hope that at no time will there ever be restrictions placed on the free expression of scientific thought. (*Applause.*) Let us determine that our discussions will be as free in the future as they have been in the past. With such determination, Institutes like our own can safely be left in the hands of their friends. Amongst those friends The Iron and Steel Institute is very happy to count Sir Oliver Franks, and I would express our gratitude to him for his kindness in coming here today and for his eloquence in proposing this toast. (*Applause.*)

"*The Guests*"

Lieut.-Colonel Sir **John Greenly,** K.C.M.G., C.B.E. (Hon. Vice-President), who proposed the toast of "*The Guests,*" said: Although I am glad to have the privilege of proposing this toast, I am mindful of the story of the toastmaster who came up to the next speaker and said, "Are you ready to speak now, Sir, or will you let them enjoy themselves a little longer?" (*Laughter.*) I am sorry that the time has come when I must stop you enjoying yourselves for a few moments. So far as I am aware, however, there is nothing in the rules of the Institute about guests sleeping after lunch, and, remembering the old adage, "After luncheon, sleep a while," I shall not be upset if they like to do so. (*Laughter.*)

When, a few weeks ago, the President invited me with great kindness and even greater temerity to propose this toast, I accepted with pleasure; but when, a few days ago, I was presented with the very formidable list of distinguished guests that we have here today, I was not sure that the temerity was not all on my side, rather than on his in asking me to undertake this duty. I should like to mention each of our distinguished guests by name, but it is now two minutes past three, and if I gave only one minute to each guest I should have to go on talking until four o'clock, and I am sure that even the most patient of you would begin to think that it was almost time for tea. I am sure that you will forgive me, therefore, if I refer by name only to a certain number.

First of all, I should like to express our deep appreciation of the fact that we have had with us Their Excellencies the French Ambassador and the American Ambassador. (*Applause.*) I say "have had" because they have had to leave, owing to pressure of important work, but with more temerity His Excellency the Minister for Luxembourg is still sitting out the session. (*Applause.*) We regard it as a great compliment that these gentlemen, in the middle of their busy and important duties, should spare the time to be with us today, and on behalf of the Institute I should like to express our gratitude to them. M. Massigli is an old and staunch friend of this country, and we are indeed fortunate to have in Britain today, to deal with the affairs of his own country and ours, such an experienced diplomat. (*Applause.*) We are particularly fortunate also in having Mr. Lewis Douglas as the representative of the great American nation (*Applause*) with which as the years go by we become more and more closely linked in friendship and understanding. We have been blessed in the Ambassadors that they have sent us in the past. Many of us remember with pleasure the privilege of knowing the late Mr. John Winant. (*Applause.*) It is fortunate that we have Mr. Douglas to follow him, because Mr. Douglas has already by his high qualities endeared himself to the people of this country. Those of us who had the good fortune a few days ago to hear his speech at the unveiling of the Roosevelt Memorial in Grosvenor Square must have been deeply impressed by his words.

To His Excellency the Minister for Luxembourg we extend a cordial welcome. (*Applause.*) We are well aware of the great services that he is rendering to this country and to his own small but lovely country, and on behalf of a united Western Europe.

I am sure that you would wish me to refer for a moment to our friend Sir Oliver Franks. We much regret that he has had to leave us. We are very proud to have with us the High Commissioners for South Africa, India, and Pakistan. (*Applause.*) I am certain that you would wish me to offer a special welcome to the two representatives of the newest of our Dominions.

We are also honoured to have here today the First Sea Lord, Admiral Sir John Cunningham, and the Vice-Chief of the Imperial General Staff, Lieut.-General Templer. (*Applause.*) No less welcome are the Presidents and Secretaries of many of the senior scientific and technical Institutions of this country. We are particularly glad to welcome the Presidents of the Iron and Steel Federation and of the British Iron and Steel Research Association, and Sir Charles Darwin, the Director of the National Physical Laboratory. We are delighted that the technical press are so well represented, and we would express our satisfaction at having many guests from oversea, from France, Belgium, Norway, Sweden, Italy, Switzerland and, last but by no means least, the United States; and in particular I should like to offer a welcome to Professor Mehl, from the Carnegie Institute of Technology, in America, and this year's Hatfield Memorial Lecturer. (*Applause.*)

I have for many years given a good deal of consideration to the question of why we propose the health of the guests, and frankly I am a little puzzled. (*Laughter.*) I watched most of them as they came in today, and they seemed to me to be in excellent health, so that I could not see why my luncheon should be disturbed by having to propose their health at the end of it. However, it is a very pleasant custom. It is always pleasant to welcome guests, both on public occasions and in one's family circle; but it makes one wonder whether we as hosts are a little nervous about the luncheon that we offer them, in case they may not feel so well after it as they were when they came (*Laughter*), but to say that is no disparagement of the Dorchester Hotel! I am reminded of the tragic little story of the schoolboy who committed suicide. The headmaster was naturally anxious to discover the cause of this sad event, and so he called the whole school together and told them the facts. As usually happens when a headmaster addresses the

school, there was a moment of complete silence, and then a small boy at the back put up his hand and said, "Please, Sir, do you think it could have been because of the food?" (*Laughter.*)

I am a little puzzled, too, as to why this toast of the guests should almost always come at the end of the proceedings, but I have come to the conclusion that it is due to the kindness of those who arrange these functions, who feel that having heard two or three first-class speeches to begin with, the guests will have reached such a state of post-prandial contentment that they will not mind very much what is said about them, or indeed whether anything is said about them at all! (*Laughter.*) One of the best speeches that I ever heard in this connection was made by a friend who had dined not wisely but a little too well, and who rose unsteadily to his feet, looked vaguely round the room, and then, turning to the Chairman, said, "Our guests, God bless them!" and sat down.

It might be a good thing if I did that now, but there is one other guest whom I must mention, because his name is coupled with this toast: Lord Clydesmuir. (*Applause.*) Many of us will remember him better as John Colville, but we were all delighted when he was recently raised to the peerage, and we congratulate him very warmly, though how long he is going to be allowed to remain in the Upper House is a matter of conjecture! (*Laughter.*) It is a matter of great pride to me that he is a fellow Carthusian, but I regret that when he left Charterhouse he chose the wrong Trinity College; however, Oxford's loss was Cambridge's gain. He has had a long and distinguished career, and it is very appropriate that his name should be associated with this toast because of his long and intimate connection with the steel industry and with kindred engineering industries. He rendered distinguished service in the House of Commons as Secretary of the Department of Overseas Trade from 1931 to 1935 and as Financial Secretary to the Treasury from 1936 to 1938. That is almost the last time we had a decent Treasury! He then became Secretary of State for Scotland, and afterwards Governor of Bombay. During part of 1945 he acted as Viceroy and Governor-General of India, at a time when India had only recently emerged from the grave dangers which had menaced her from the East. It is a romantic touch that two of our great Pro-Consuls should have taken their titles from two great Scottish rivers, John Buchan Lord Tweedsmuir and John Colville Lord Clydesmuir. (*Applause.*)

The Right Hon. Lord **Clydesmuir,** P.C., G.C.I.E., who responded, said: I rise with pleasure but with some trepidation to reply to this toast, so happily proposed by Sir John Greenly—trepidation for the same reason that he said affected him. When I looked through the list of those for whom I have been chosen to reply, I found so many who were so eminent in so many spheres in so many different countries that I felt but a minor prophet to speak for such a galaxy of talent. I can speak for them all, however, in saying that we have no suicidal tendencies on account of our lunch; we have nothing but contentment, and even repletion. (*Laughter.*)

I appreciate the honour of replying for the guests, but at best I am a very bogus guest myself, because I have been a member of this Institute for almost thirty years, under another name. (*Laughter.*) About fifteen years ago, however, I strayed into the far country of politics and oversea administration, and have only now come back to my father's house. I have a confession to make. On my return, I was about to write out a cheque for this luncheon, "exclusive of wines but inclusive of gratuities," when an invitation came to me as a guest; and I should have been no true son of Scotland if I had not put away my cheque-book. (*Laughter.*) Perhaps it was due to the Treasury training of which Sir John spoke!

No doubt the reason which prompted the Institute to invite me was that which prompted the father to kill the fatted calf for the prodigal, and we guests give you thanks for the fatted calf of physical and intellectual fare, for which we are indeed grateful. We have been amply regaled in body and mind.

There are two Institutions in this country which are much in the public mind today: the steel trade and the House of Lords. In some ways they are coupled in the public mind, perhaps wrongly. (*Laughter.*) There is a feeling that the sword of Damocles hangs over both, yet I would hazard the view that there is a good expectation of life for both. (*Applause.*) In the gracious country from which I have just come, India, there is a widespread belief that one's future existence on this earth is conditioned by one's behaviour in one's present existence. If this is so I think that the steel trade is entitled to a pretty good break, because it is playing such an important part in the nation's recovery at the present time.

There is a very salutary rule in the Upper Chamber that when the legislators there find the speech of one of their number too wearisome, and reach what may be called the elastic limit of endurance, it is competent for them to move "That the noble Lord be no longer heard"—nor is he if the motion is carried; he sits down in resentful silence. You may be tempted to move such a motion if I go on for too long; but, if brief, my effort to show gratitude is sincere. I wish to say to my friend of long standing, Sir Andrew McCance, that we are indeed appreciative of this function; and I speak for a widely representative gathering, drawn from many countries and many spheres of life, a united nations organization with no one minded to apply a veto, when I say that we are deeply grateful to you for your entertainment of us.

No invention of science has yet wrested from steel the first place in the economy of a great nation, and in your Institute the steel industry has a body to which it can turn and with which it will never be disappointed. The scope of the Institute is unparalleled. It is indeed a city set on a hill to which we have come today, and we are proud and grateful. In thanking you once more, I should like to express the hope that the President's term of office may be happy and fruitful. (*Applause.*)

The proceedings then terminated.

DISCUSSION ON PAPERS

DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Correspondence on the Paper—

SOME PROPERTIES OF TITANIUM STEELS*

By L. Northcott and D. McLean

Messieurs **Pierre Laurent** and **Michel Eudier** (Centre National de la Recherche Scientifique, Paris) wrote: The authors attribute the disappearance of ageing after cold-work in titanium steels to the strong affinity of titanium for carbon. For that, according to them, the the titanium content must be greater than that corresponding to the composition TiC, *i.e.*, the ratio Ti%/C% must exceed 6 (page 504). The writers wish to comment on this.

(1) The exact determination of the titanium content at which the ageing after cold-work disappears—or, what comes to the same thing, the ratio Ti%/C%—is not made clear. This ratio (Table X) in fact jumps suddenly from 2·8 for steel *A*0·25, which ages, to 6 for steel *A*0·5, which does not.

(2) Comstock and Lewis,[1] using steels with 0·15% of carbon, showed that the amount of titanium necessary to eliminate ageing after cold-work varied with the treatment applied to the steel, and that in all the cases examined it was sufficient to have $Ti\%/C\% > 1{\cdot}34$.

(3) Further, Eilender, Cornelius and Knüppel,[2] and Edwards, Jones and Walters,[3] confirming the hypothesis of Houdremont,[4] showed that oxygen has no influence on ageing after cold-work, carbon has little effect, but nitrogen seems to be the preponderating element. It therefore seems inadvisable to draw conclusions before the relations of the titanium to these elements have been determined.

The authors have probably observed a flat portion in the elastic-limit curve for low-titanium steels. Have they obtained any confirmation of Dies' assertion[5] that this flat part disappears when the carbide TiC appears?

Mr. **G. A Knight** (The Pressed Steel Co., Ltd., Cowley) wrote: I have read this comprehensive paper on the properties of some titanium steels with interest, particularly so the section dealing with the effect on quench- and strain-ageing. The demand for non-ageing steel sheet in this country remains largely unappeased, although a useful tonnage of aluminium-treated non-ageing steel is now produced in the U.S.A. Any development, which would lead to a greater understanding of ageing phenomena, and thus to the production of a steel sheet which would not be susceptible to deterioration of deep-drawing and pressing properties, is to be welcomed.

The true cause of strain-ageing is still a matter of some controversy in this country, although recent developments in the U.S.A., particularly by Low and Gensamer[6] and by S. Epstein,[7] tend ever to point the accusing finger at nitrogen. Low and Gensamer have shown that this element, when present to the small extent of 0·001%, does cause the yield point to return—an acknowledged strain-ageing phenomenon.

I would refer in particular to the curves in the authors' Fig. 12, which shows how the tensile properties vary with temperature. The gap in the curves for the low-carbon steels between 150° and 300° C. includes the very important region, sometimes referred to as the "blue-brittle" region. Kenyon and Burns[8] have shown, and I myself have confirmed, that non-ageing low-carbon steels of the aluminium-killed type, show a decided drop in tensile strength when tested at 205° C. Rimming steels, on the other hand, show a definite peak in the curve in this region, the exact position of the peak depending on the prior history of the sample, and varying according to whether it was normalized, cold-reduced, or sub-critically annealed. The increase in strength also appears to be in direct relationship to the nitrogen content. Bessemer-type steels which have quite high nitrogen contents give very much higher tensile figures at about 205° C., I myself having had samples in which the tensile strength at 205° C. was as much as 13,000 lb./sq. in. above that at room temperature. This phenomenon has led many investigators to believe that this is due to instantaneous ageing during deformation. The results of any tests therefore that would complete the curves in Fig. 12 would be of considerable interest in assessing the effect of titanium on the ageing characteristics. A study of Kenyon and Burns' results appears to indicate that, as long as the tensile strength at 205° C. is no greater than that at room temperature, the material is relatively stable against changes due to room-temperature ageing.

It is a well-known fact that nitrogen can be controlled in the open-hearth by the addition of such elements as aluminium, zirconium, and titanium, which react with nitrogen, changing it to inactive forms. It is perhaps rather unfortunate that these elements are strong deoxidizers as well as nitride-formers, and therefore their use in sufficient quantity to fix the nitrogen will result in killed steels. The rôle of aluminium, therefore, cannot be entirely overlooked, as it is a valuable addition agent in the control of the oxygen, and renders possible the economical use of other elements such as titanium, zirconium, or vanadium, which is likely to be otherwise expensive, if sufficient of these has to be added to deal

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with oxygen as well as nitrogen. The authors have shown that an excess of titanium over that necessary to form TiC is required to reduce strain-ageing to a minimum. I suggest that this is supporting evidence that nitrogen is really the " nigger in the wood pile " and that this excess combines with nitrogen to form the nitride which has no harmful precipitation tendencies.

According to Jones'[9] results, the titanium content need only be that required to form TiC in order to prevent quench-ageing, and this tends to support the views of other investigators in the United States that nitrogen is responsible for strain-ageing and carbon for quench-ageing. Thus carbon in aluminium-killed steel is not fixed by the aluminium and this steel is therefore subject to quench-ageing. The strain-ageing, however, is reduced to a minimum owing to the nitrogen being fixed by the aluminium. The authors' views on this latter hypothesis would indeed be interesting.

AUTHORS' REPLY

Dr. **Northcott** and Mr. **McLean** wrote in reply : Messieurs Laurent and Eudier are correct in saying that our results do not fix precisely the Ti/C ratio at which strain-ageing disappears since they only show that it disappears at a ratio between three and six. We therefore made the conservative statement " nearly six times " on page 505 (not " must exceed six," the statement attributed to us). Actually, we were guided in this by the quench-age-hardening results, which show that a ratio greater than four is necessary to prevent age-hardening, since the two processes probably have much in common.

We do not exclude nitrogen from playing a part in these phenomena, for on page 504 we say " that part of this titanium in excess of the Ti/C ratio may be required for combination with the nitrogen present." However, Messrs. Laurent and Eudier have surely drawn an impermissible conclusion from the work of Edwards, Jones, and Walters,[3] and the later paper by Edwards, Phillips, and Jones,[10] in saying that it is there shown that nitrogen is the important element ; that is certainly not the position taken up by these authors themselves, and a study of the papers makes it very difficult to see how their conclusions can be altered. Eilender, Cornelius, and Knüppel,[2] on the other hand, do conclude that their results show nitrogen to be the most important element. However, their results are for strain-age embrittlement as determined by a notched-bar test, so the well-known complication of the tough-to-brittle transition enters the picture since with notched bars it will occur in the neighbourhood of room temperature. It is quite possible from their results that in the untreated condition this temperature was in the neighbourhood of room temperature for their high-carbon material, but below room temperature for their low-carbon material, so that room-temperature notched-bar tests would give a low value associated with a partly brittle fracture in the former case and a high value associated with a tough, fibrous fracture in the latter. Straining and ageing have the effect of raising the transition temperature sufficiently for room-temperature notched-bar tests to yield low impact strengths and a brittle fracture in both cases. Consequently, with the low-carbon material the difference between the two results would measure the full difference between tough and brittle behaviour, but with high-carbon material would measure only part of this difference, that between partly brittle and fully brittle behaviour. Thus the conclusion of Eilender, Cornelius, and Knüppel is an impermissible deduction from their results. Before a firm conclusion can be drawn it would be necessary to determine the full curves of impact strength against temperature and to ascertain by how much the various elements influence the shift in tough-to-brittle transition temperature on straining and ageing. The situation is the same as that arising in connection with temper-brittleness, mild steel, etc., where determination of notched-bar strengths at one temperature (or, more probably, at a variable room temperature) can give anomalous results.

It should perhaps be added that in a ferrous material containing more nitrogen than carbon, the Ti/N ratio would probably be the determining factor.

We do not understand the statement that we have probably observed a flat portion in the elastic-limit curve for low-titanium steels as applying to our strain-ageing results, since the point involved is whether the yield point and ultimate tensile strength are changed by ageing rather than how they vary with composition.

Mr. Knight draws attention to one of the possibly valuable commercial uses of titanium in steel. Of course, as far as commercial practice is concerned, it does not matter whether the ageing phenomena are due to nitrogen, carbon, or both, since titanium combines with both. But it is important to know the rôle played by each to understand the mechanism of the ageing process. Actually, Low and Gensamer[6] show that exceedingly small quantities of either carbon or nitrogen, and not just nitrogen alone, as Mr. Knight suggests, produce strain-ageing and a sudden yield point, and this would be expected on the " equilibrium segregation "[11] theory.

With mild steel, carbon is likely to be far more important than nitrogen for quench-ageing because it is present in much greater quantity. It may be because Jones'[9] steels had a normal, low-nitrogen content that a 4/1 Ti/C ratio was sufficient to prevent quench-ageing, the titanium required for combination with the nitrogen being relatively negligible. Appreciable quantities of titanium nitride were present in our steels, and no more than the 4/1 Ti/C ratio was required to provide the additional titanium combined with this nitrogen. There is every reason to expect that nitrogen in sufficient quantity could cause age-hardening, but much more than the usual contents would be necessary.

Mr. Knight's final suggestion is an interesting one and agrees with some, but not all, of the evidence. For example, as mentioned above, Low and Gensamer show that a very small amount of carbon causes strain-ageing. It is difficult to explain this discrepancy but it cannot be ignored.

Parts of our reply to Messrs. Laurent and Eudier are pertinent to the points raised here.

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Correspondence on the Paper—

SPECTROGRAPHIC ANALYSIS OF LOW-ALLOY STEELS*

By H. T. Shirley, E. Elliott, and Joyce Meeds

Mr. **M. Milbourn** (Imperial Chemical Industries, Ltd., Metals Division) wrote: The interest of this contribution to the literature on spectrographic analysis lies mainly in the statistical treatment of the results, leading to an assessment of magnitude of the contributions to total variability made by various factors in the analysis of steel. It is now generally recognized that a better reproducibility is obtained when analysing steels than when analysing aluminium alloys, for instance, the difference being due mainly to factors associated with the source and the electrodes, but the figures deduced by the authors for plate and reading errors should be applicable to any type of alloy. There are certain details in the paper, however, which make one hesitate to adopt such a procedure, because it involves predicting future behaviour from the results of past tests.

It is known, for instance, that plates that are nominally of the same type may vary from batch to batch, and it would have been preferable if tests had been carried out on plates from different batches, because those actually used may not be representative of the general standard supplied by the manufacturers. A similar argument could be applied to the employment of one sample only for all tests, although this would probably have a greater effect on source variability than on plate variability, since the former includes that due to electrodes.

A further difficulty lies in the establishment of statistical stability, which is essential before predictions can be made. If it is not present, unassigned factors may be occasionally exercising a predominant influence, and there is no assurance regarding their possible effect in the future. In statistical terms, stability indicates that the samples have been taken from a homogeneous population, and if, as in the data under consideration, the population is non-homogeneous, owing to the operation of assignable causes, then residual variations should be homogeneous before well-founded deductions can be made regarding the influence of these assignable causes. There is some evidence in Table VI of the paper that the results are not fully stable, and, although the absence of detailed figures precludes the use of significance tests, one or two examples may be quoted. Thus, there is a large difference between the source standard deviations for silicon on plates *RXB* 303 and 307, as well as for nickel on plates 251 and 252; among the figures for plate standard deviation, those for nickel on plates 280 and 305 may be noted, together with the fact that the figures for molybdenum on plates 343 and 344 are considerably higher than the corresponding manganese figures, whereas the behaviour of the two elements is comparable on other plates.

The authors' rejection on page 395 of the customary statistical procedure of dividing by the number of degrees of freedom in calculating standard deviations may also be questioned. Their practice, in fact, is not consistent, because they have employed the correct divisor in calculating plate standard deviations on page 394. Assuming that d_p is the difference between top and bottom readings for one spectrogram, then each reading differs from the mean of the two by $d_p/2$, and the variance for the one spectrogram is $2(d_p/2)^2/(2-1)$, *i.e.*, $d_p^2/2$. For 30 spectrograms the variance is $(\Sigma d_p^2)/(2 \times 30)$, which is the formula they have used, and it allows only one degree of freedom to each pair of results. The valuable work of statisticians, such as Professor R. A. Fisher, who have done so much in elucidating the correct use of degrees of freedom, could hardly be discarded on the evidence brought forward in Table II of the paper. An alternative explanation of these results is that the nine individual readings on which they are based are not a truly random sample, in that the figures are associated in such a way that the population variance is underestimated when it is calculated from the nine individual readings. The difficulty that apparently negative values of variance due to plate are sometimes obtained, when the strictly correct value for measurement variance is employed, can be adequately explained by sampling errors when the plate variance is small or non-significant. Although the correction factors for reading errors are small, the possibility that other similar associations may be present in the calculations cannot be ignored, and the final results would have carried more authority if accepted methods had been employed.

The above comments bear on the general conclusions of the paper, but they also indicate ways in which painstaking work undertaken by the authors could be employed very usefully in future investigations. Experiments designed statistically to study selected factors on a wider basis could now be undertaken by the authors or by other investigators, with a quantitative knowledge of the probable amount of variability to be expected, and hence of the number of tests needed to obtain a required level of accuracy. It is quite likely that a considerable number of factors could be studied more completely with fewer tests than have been employed in the experiments under consideration now that preliminary data have been collected, and the writer will hope to be able to employ the results in planning his own experimental work.

AUTHORS' REPLY

Mr. **H. T. Shirley,** Mr. **E. Elliott,** and Miss **J. Meeds** wrote in reply: The authors would agree with the general principles underlying Mr. Milbourn's comments, but consider that the practical significance of the disturbing factors discussed is considerably less than might be inferred.

They agree, for example, that it would be of considerable interest to check the consistency of behaviour of a given type of plate by taking periodic samples from different batches, but since the checking of a simple plate involves upwards of 900 readings, a limit had to be put on the number of variables which could be included, particularly in view of the urgent requirements of work in other directions, as for example, in relation to source contribution. They would say, however, that their general experience over large numbers of plates is such as to indicate that the major differences between the types of plates tested are consistently apparent. As a direct check, in view of Mr. Milbourn's comments, they have determined σ_{PC} for an Ilford Thin-Film Half-Tone plate and for a Kodak *B*10 plate from recent deliveries. Processing and reading were carried out as for the series covered by Table VI of the paper, and the mean values for σ_{PC} for the five elements were found to be 0·0021 and 0·0031 respectively. These values are in excellent

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agreement with the overall mean results of 0·0019 and 0·0031 quoted in the paper for plates of these two types purchased more than two years ago.

Mr. Milbourn's second point concerns the necessity of statistical stability for fully accurate prediction, with particular reference to source contribution. While obviously agreeing with this in principle, the authors considered that, where existing knowledge and technique had not permitted the development of greater stability or a more complete analysis of the situation, deductions from the data were still of definite value, provided due allowance were made for the variability when quantitatively assessing the position. They were careful to point out the existence of such variation in their consideration of the values for σ_{SC} (page 399), and to limit this consideration to a broad general survey. Clearly a good deal of further work is required here in respect of source design and sample response, and such work is in progress.

In Table VII of the paper the authors show that there is little overall difference in plate contribution in respect of the various line-pairs used. There is no point, therefore, in limiting consideration of variations in σ_{PC} to particular line-pairs. Considering the nature of the variable studied, it does not seem surprising that individual values of σ_{PC} from 30 readings should show appreciable variation, but a study of the following summary of maximum and minimum values at least leaves the authors in no doubt as to the considerable inferiority of the Ilford Ordinary plates, or to the equally obvious superiority of the Ilford Thin-Film Half-Tone plates:

Type of Plate	No. of Results	Min. Value	Max. Value	Overall Mean Value
Kodak *B*20	65	0·0024	0·0049	0·0038
Kodak *B*5	25	0·0017	0·0048	0·0030
Kodak *B*10	15	0·0020	0·0039	0·0031
Eastman Kodak *S*1	10	0·0018	0·0041	0·0032
Ilford Thin-Film Half-Tone	20	0·0007	0·0028	0·0019
Ilford Ordinary	10	0·0043	0·0091	0·0070

On pages 395 and 396 of the paper the authors gave in some detail their reasons for preferring $(n - \frac{1}{2})$ to $(n - 1)$ as denominator in respect of residual reading errors, as determined within the framework of their particular procedure. While their argument may have been more related to common-sense consideration of approximate values than to strict mathematical theory, they showed in Table IV that no serious misinterpretation was likely to arise from any uncertainty as to this value. In view of Mr. Milbourn's remarks, they would again draw attention to the small practical importance of the point in connection with the values of σ_{PC} and σ_{SC} in the calculation of which these residual reading-error corrections were used. The main effect of the use of $(n - 1)$ in place of $(n - \frac{1}{2})$ would be to exaggerate somewhat the relative "goodness" of the best plates in respect of σ_{PC}, and to give small increases in the values of σ_{SC}, noticeable only in the case of the lowest values. This is illustrated by the following values for σ_{PC}[1] and σ_{SC}[1], based on reading-error corrections obtained with $(n - 1)$ as the denominator, compared with the corresponding values for σ_{PC} and σ_{SC} taken from Table IV of the paper and calculated with $(n - \frac{1}{2})$ as the denominator:

Plate	Element	σ_{PC}	σ_{PC}[1]	σ_{SC}	σ_{SC}[1]
RXB328	Silicon	0·0017	0·0011	0·0036	0·0036
RXB328	Chromium	0·0018	0·0013	0·0032	0·0033
RXB328	Nickel	0·0032	0·0029	0·0016	0·0018
RXB305	Chromium	0·0032	0·0029	0·0056	0·0056
RXB263	Chromium	0·0048	0·0046	0·0064	0·0064

In calculating the general reading error, σ_R, the authors adhered to the $(n - 1)$ rule for the reasons given on pages 401 and 402 of the paper. In this case, therefore, Mr. Milbourn's criticism does not apply.

In conclusion, the authors would like to thank Mr. Milbourn for his interesting comments, and they are glad to note that he is likely to find their results of value in his further development of the subject.

Correspondence on the Paper—

MICRO-EXAMINATION AND ELECTRODE-POTENTIAL MEASUREMENTS OF TEMPER-BRITTLE STEELS*

By D. McLean, B.Sc., and L. Northcott, D.Sc.

Dr. **H. A. Dickie** (Stewarts and Lloyds, Ltd., Corby) wrote: I was interested to note that the passage of 20 years since I endeavoured to throw some light on this phenomenon has not yet, apparently, resulted in an agreed explanation, although one might have expected that more modern and penetrating aids would have settled the issue. It seems that recent investigators, including the present authors, are gradually approaching an explanation very similar to that given at the early date mentioned.[1, 2]

The authors favour the grain-boundary theory and produce a good deal of evidence to support it. They also consider that the element carbon is responsible, but they depart from the usual carbide theory and postulate a phase like martensite. This is because the grain-boundary constituent will not etch with the same reagent as the normal carbide in the steel (or *vice versa*), or because it does not readily coalesce into separate particles on prolonged heating.

The phase formed at the boundary could scarcely be martensite itself since this is unstable at temperatures at which the phase responsible for temper-brittleness is formed, and would break down into ferrite and carbide. It is not quite clear why the phase could not be carbide, of a composition different from the normal carbide which, in the case of the authors' steels, will contain elements other than iron, and particularly chromium, molybdenum, or manganese in the different cases.

It may also be pointed out that iron carbide is not a true compound (ionic or valency crystal). It has some of the properties of a solid solution of fixed composition and has definite resemblances to martensite in the anisotropic arrangement of the iron atoms (body-centred-tetragonal for martensite,[3] face-centred-orthorhombic for cementite[4, 5]) with the carbon atoms in interstices, in each case, and with similar hardness (900 for martensite, 820 for cementite[6]) and similar density (7·70–7·77 for martensite, 7·73 for cementite, calculated from the lattice dimensions).

Both phases have, therefore, similarities of type and this would also very likely be true of other possible

* *Journal of The Iron and Steel Institute*, 1948, vol. 158, Feb., p. 169.

interstitial solutions or compounds, such as nitrides or carbo-nitrides which might conceivably be found to contribute. It can now, it would seem, be assumed that the essence of the matter is the expulsion of interstitial atoms (or ions) to the grain boundaries, with the formation of a separate phase or concentrated zone there.

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AUTHORS' REPLY

Dr. **Northcott** and Mr. **McLean** wrote in reply: Dr. Dickie's contribution has been read with interest, but has left us with the feeling that we may not have completely put over our views as to the cause of temper-brittleness. In our opinion the present explanation is very different from that put forward by Dr. Dickie and to which he refers; Dr. Dickie's view was that precipitation of carbide as a separate phase along the grain boundaries was responsible. In the present work, we would like to make it clear that a separate phase does not, nor need not, occur at the grain boundary, but merely a high concentration of solute atoms (which may be, but are not necessarily, carbon) owing to the distorted lattice there. The concentration falls smoothly as one moves away from the boundary into a less-distorted lattice. As explained briefly in the paper, this distribution of the solute elements has the minimum energy. These points are discussed more fully in reference 7 of the paper. It follows that on this view the grain-boundary "martensite" will not decompose into ferrite and carbide and that it should not be regarded as a separate carbide phase.

In our view it is probable that temper-brittleness may result from the boundary segregation of a number of elements of which carbon is only one.

Correspondence on the Paper—

GRAPHITE FORMATION IN CAST IRONS AND IN NICKEL–CARBON AND COLBALT–CARBON ALLOYS* *by H. Morrogh and W. J. Williams*

Dr. **F. Pobořil** (The Vítkovice Steel Works, N.C., Ostrava, Czechoslovakia) wrote: The authors illustrate the constitution of the iron-rich corner of the iron–carbon–silicon system, according to Jass and Hanemann.[1] In Jass and Hanemann's original publication it can be seen that they have determined experimentally only the point L of the invariant-equilibrium four-phase plane α–γ–C–L. A. Kříž and the writer have in a much earlier work[2] determined experimentally all the points of the invariant equilibrium, and E. S. Greiner, Marsh, and Stoughton have used their work in the well-known monograph[3] on the alloys of iron and silicon.

Figure A is a reproduction of Fig. 23 of the writer's paper, giving the isothermal section at 1170° C. of the stable system, *i.e.*, just at the temperature of invariant equilibrium, which shows the concentrations of the points α, γ, and L. The following is a comparison of these concentrations according to Jass and Hanemann with those according to Kříž and the writer:

	α	γ	L
Jass and Hanemann	0·15% C 10·2% Si	0·45% C 8·2% Si	2·45% C 6·0% Si
Kříž and Pobořil	0·22% C 9·7% Si	0·52% C 7·7% Si	2·54% C 6·4% Si

It will be seen that the corresponding values are in good agreement, especially those of the point L, indicating that the interpretation of the iron–carbon–silicon constitution given in the paper by Kříz and the writer is correct.

AUTHORS' REPLY

Mr. **Morrogh** and Mr. **Williams** wrote in reply: The authors agree with Dr. Pobořil that there is substantial agreement between the work of Kříz and Pobořil and Jass and Hanemann. In the paper in question no attempt was made to discuss the iron–carbon–silicon system in any great detail and the object of quoting the work of Jass and Hanemann was merely to give a general picture of the mechanism of the binary complex solidification in the ternary system. The work of Jass and Hanemann is largely an attempt to establish the position of the

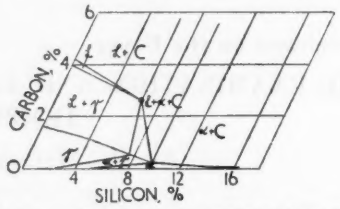

Fig. A—Isothermal section at 1170° C. (stable system) (Kříž and Pobořil[2])

binary complex trough and this was done very carefully with materials of a higher degree of purity than those used by Kříž and Pobořil. The authors are well aware of the important contribution to this subject made by Kříž and Pobořil and they feel that Jass and Hanemann made considerable use of their earlier contribution to the subject.

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* *Journal of The Iron and Steel Institute*, 1947, vol. 155, Mar., p. 321.

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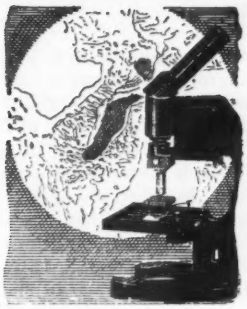

Studies on Anti-Fouling Compositions

By H. Barnes, B.A., B.Sc., Ph.D., F.R.I.C.

FOREWORD

This paper forms part of a series of studies on anti-fouling compositions. The first three papers were published in the December, 1947, issue of the *Journal*. Part I was a general introduction to the whole series. Part II described the probable reactions occurring between the components during preparation of the varnish, and Part III gave details of a study of the rate of loss of material from a series of varnish media immersed in the sea over two consecutive 40-day periods. (It should be noted that the remarks in the previous Foreword describing Part III should refer to " the rate of loss of material," and not as printed.) The present paper, Part IV, determines critical leaching rates for a number of common fouling organisms and compares copper loss under service and raft exposure conditions.

Part IV—The Relationship between Leaching Rate, Copper Loss, and Anti-Fouling Performance, under Raft and Service Conditions

SYNOPSIS

Following a discussion of the factors affecting the rate of release of cuprous oxide from anti-fouling compositions, consideration is given to the methods of storage of leaching slides in order to compare anti-fouling behaviour with leaching-rate determination. Sea storage is considered desirable when large numbers of compositions are to be tested. The relation between the loss on raft panels and that given by leaching-rate determinations has been investigated.

By leaching-rate determinations and assessment data on replicate panels, the critical leaching rates necessary to prevent the establishment of some important fouling organisms have been determined for average exposure conditions. It is shown that a rate of 10 μg. sq. cm./day will prevent the settlement of forms other than algæ.

Data are presented on the loss of copper from experimental compositions under varying conditions of service. It is shown that the loss in service is greater than that from the same composition when exposed on the raft.

Introduction

A NUMBER of investigations has suggested that the anti-fouling action of cuprous oxide compositions is related to their loss of copper, with the consequent formation of a layer of poisonous solution over the surface of the paint (*see* Part I for references). Detailed consideration will now be given to this rate of loss of copper. The rate of loss of copper from an immersed composition is dependent on the formulation, that is, on its chemical characteristics, and upon a number of external factors. Ferry and Carritt[1] have indicated the nature of the chemical reactions involved in the solution of cuprous oxide and have shown that for a given area of exposed particles the rate of solution depends upon the chloride concentration and the *p*H of the external solution. The rate of flow of water over the panels (or in experimental work, the rate of agitation of the solution) can also, within certain limits, be a rate-determining factor in the process of dissolution. These same variables are also concerned in the control of the rate of solution of rosin, as a result of which particulate cuprous oxide is exposed and made available to attack. In the conditions found in the open

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Dr. H. Barnes, formerly Investigator to the Marine Corrosion Sub-Committee of The Iron and Steel Institute, is now with the Scottish Marine Biological Association, Millport.

sea the salinity and *p*H do not change greatly in magnitude and as a first approximation they may be regarded as constant at a raft site such as Millport. By contrast, the rate of flow of water over the plate varies with the state of the tide, from virtually zero at slack water to approximately 2–3 knots on the ebb. Further, changes in the film take place during immersion, so that the rate of loss under identical environmental conditions changes with time. It is virtually impossible to reproduce all these variables during the storage of slides under laboratory conditions so as to study the relation between loss of copper and anti-fouling performance. Fortunately, such duplication is not necessary. If leaching slides are stored in the sea by exposure on a raft, all that is required for a leaching-rate *test* is some standard experimental technique whereby it is possible to measure a rate of loss of copper bearing a constant relation to the rate of loss under exposure conditions throughout the exposure period. If leaching slides are, therefore, stored on the raft, and the rate of loss of copper is determined under standard conditions using sea water brought in at the same time as the slides, then the leaching rate so obtained may be considered as a measure of the mean rate of loss on the raft, at that time, over a whole tidal cycle. This method has been used in all the work now reported. It is by far the simplest method and has the only disadvantage that, due to rough weather it may not always be possible to get the slides from the raft on any particular day ; however, only on a very few occasions has it been impossible to bring in the slides at least within a day or two of the required time. The method does, of course, require a raft site adjacent to facilities for carrying out the leaching-rate test. The alternative, namely, laboratory storage of the leaching slides under standard conditions, as used by some workers in this field (*see*, for example, Hanson and Jervis[8]), and comparison of their leaching rates with raft performance, presents a more complicated problem; the leaching test in these circumstances gives a measure of the rate of loss at any time under the standard storage conditions. (Such standard storage conditions are difficult to maintain when several hundred test slides are being simultaneously investigated.) It is then necessary to know the relationship between these storage conditions and those obtaining for sea-exposed panels for both the leaching rate of identical paint systems and the changes of a given system with time under the two conditions of storage. In the original work of Harris[2] laboratory storage was employed, the leaching slides being kept in tanks of running sea water between the leaching-rate determinations. Further extensive work, both on leaching rates and real rate of loss determined by analysis, has only served to indicate the complications which arise when this type of storage is used ; although the results may give an indication of performance, a reliable correlation with anti-fouling action or length of life is difficult to obtain. As already indicated, this method has been completely abandoned in favour of storage of leaching slides on the raft. In applying the results of the leaching-rate work to practical conditions encountered in service, the changes in environmental conditions, *e.g.*, salinity, will have to be taken into account when considering the leaching-rate data for the composition used. This should be a subject for further investigation and not a reason for abandoning a standard test.

A direct relation at any time between the behaviour of a composition towards settling organisms and its leaching rate might be expected if the latter is a measure of the rate of loss throughout the exposure period. To be able to compute the length of life the leaching-rate/copper-loss ratio should also be known.

Service conditions introduce a new set of values for some of the variables affecting the rate of loss. Any relation between leaching rate and anti-fouling efficiency should remain unchanged, since fouling only settles when a ship is in port, but the changes of leaching rate with time might be expected to be different from those of the raft exposures.

THE RELATIONSHIP BETWEEN LOSS OF COPPER AND LEACHING RATE

The leaching technique employed has been given (Part I).* The volume of leachate and the paint area were constant throughout, and fresh sea water was used, the *p*H and temperature being uncontrolled. The bubbling rate was checked at the beginning of each run. In all these determinations it is essential that retardation of the rate of solution should not take place by accumulation of the products of leaching in the leaching bath : there is no danger of this with any moderate leaching rates. If 0·5 μg./ml. is taken as the limit of safety (Ketchum *et alia*[3]), a leaching rate of up to 15 μg./sq. cm./day is unaffected by such factors, but experience has indicated that this figure

* *Journal of The Iron and Steel Institute*, 1947, vol. 157, Dec., pp. 587–590.

Table I

RATE OF LOSS IN LEACHING TEST AND IN SEA FOR COMPOSITIONS 17H, 21H, AND 25H

Mean Rate of Copper Loss, μg. sq. cm. day									
Composition No.	17H			21H			25H		
Time of Exposure, days	Analysis	Leaching Test	Ratio	Analysis	Leaching Test	Ratio	Analysis	Leaching Test	Ratio
30	12·7	15·6	1·23	9·3	10·8	1·16	9·3	12·3	1·32
32	7·0	8·9	1·27	9·0	13·2	1·47	15·5	17·6	1·14
32	7·2	7·7	1·07	9·9	14·2	1·44	13·6	15·5	1·14
30	...	...	...	8·8	11·8	1·34	...	...	...

can be considerably exceeded with many of the compositions investigated without incurring large errors, as will be shown in Part V of the series.

Replicate slides were painted for any given series, and leaching-rate determinations were made on some of these at intervals throughout their exposure. In addition, some of these slides were periodically withdrawn, and after washing and drying, the paint was scraped off and analysed for its copper content. The rate of loss was computed from these results and from the known copper content of the original composition. The periods between withdrawal were varied, the shortest being determined by the reliability of the analytical methods for obtaining significant copper losses. It should be emphasized that extended experience with leaching-rate work has indicated that variations of 10% in the leaching rate (particularly in the early stages) may be obtained on replicate slides painted at the same time, and when the results are interpreted it must be remembered that the analyses are done on such replicates.

Table I gives some results of the comparison of the actual rate of loss of copper found by analysis and the mean leaching rate over successive exposure periods, each of approximately one month, found by the leaching-rate determinations (obtained from the area under the leaching-rate/time graph) for three compositions, 17H, 21H, and 25H. These compositions contained 12, 18, and 24% of cuprous oxide, respectively, and had a constant pigment content of 52% and a varnish with a rosin/binder ratio of 4·3/1.

A large number of compositions has been investigated in this way and the ratio of the rate found by analysis to that given by the leaching-rate determinations is almost always of the same order. The results in Table II may be quoted since they show values for compositions with a much higher poison content (29H, with 52% of cuprous oxide in a rosin–bedesol, stand oil varnish) and for an entirely different type of composition (YC, with cuprous oxide in a copper soap lanoline varnish).

The values quoted above for 17H were for a composition which had been stored for several months : on a freshly prepared batch, although both the rates are very different, the ratio is of the same order, as indicated by Table III.

The incorporation of mercuric oxide into a composition had no significant effect on the relationship

Table II

RATE OF LOSS IN LEACHING TEST AND IN SEA FOR COMPOSITIONS 29H AND YC

Mean Rate of Copper Loss, μg./sq. cm./day						
Composition No.	29H			YC		
Time of Exposure, days	Analysis	Leaching Test	Ratio	Analysis	Leaching Test	Ratio
31	106·4	50·9	0·48	96·6	45·7	0·47
32	38·5	34·3	0·89	...	...	...
39	19·5	24·1	1·24	...	...	...
106	...	...	...	18·9	23·7	1·25

Table III

RATE OF LOSS IN LEACHING TEST AND IN SEA FOR COMPOSITION 17H

Mean Rate of Copper Loss, μg./sq. cm./day			
Composition No.	17H		
Time of Exposure, days	Analysis	Leaching Test	Ratio
34	22·4	30·3	1·35
30	12·7	16·7	1·32

between the two rates : thus in 24H (equivalent to 21H but with 6% of the filler replaced by mercuric oxide) over a period of 60 days the ratio was 1·2. With the exception of low values for the initial stages of compositions such as YC and 29H the mean value of the ratio for all compositions investigated is approximately 1·2.

The low values of the ratio for the early periods of YC and 29H are due to the fact that with the high rates of loss obtained with these compositions in the early stages of soaking, the conditions in the 4-hr. leaching test are not equivalent to those appertaining when the rate of loss is of the order of 10–15 μg./sq. cm./day. In the latter case no significant reduction in the rate of loss is brought about by accumulation of copper in the leaching bath, *i.e.*, the rate is constant throughout the 4-hr. leaching. That this is not so for compositions with high rates of loss is indicated by Table IV, which gives the concentration in the leaching bath with increasing time and the calculated equivalent rate for YC during the early stages. Clearly, the rate falls off after the first hour ; indeed, after 2 hr. leaching the solution is approaching saturation with respect to copper.

In order to be comparable with moderate leaching rates the leaching period should be reduced for compositions with such a high rate of loss. It is for this reason that the ratios shown for the early periods of YC and 29H, with their high initial rates of loss, are lower than those found for their later stages or for a composition with a lower leaching rate throughout.

THE LEACHING RATE AND SETTLEMENT OF ORGANISMS

The mode of settlement of organisms on exposed surfaces is a phenomenon of great complexity as yet incompletely understood, and it is not proposed to

Table IV

ACCUMULATION OF COPPER IN LEACHING BATH WITH HIGH LEACHING RATE COMPOSITIONS

Leaching Time, hr.	Concentration of Copper in Leaching Bath, mg./litre	Equivalent Leaching Rate, μg./sq. cm./day
0·25	0·45	200
0·50	0·92	206
1·00	1·70	190
2·00	3·85	214
3·00	4·33	162
4·00	4·52	126

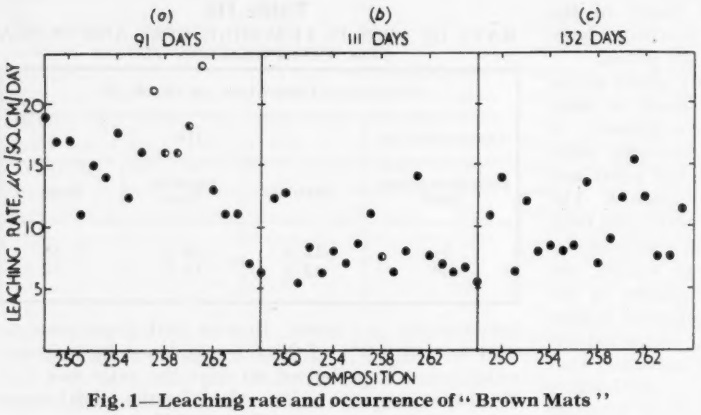

Fig. 1—Leaching rate and occurrence of " Brown Mats "

discuss in detail this problem in relation to leaching rate. However, from the point of view of the leaching-rate *test* it must be established that anti-fouling action is correlated with performance, for under the conditions of storage used there should be a direct correlation between the rate of loss and the anti-fouling action at any stage in the history of the exposed panel if the leaching process is of fundamental importance in preventing settlement. Analysis of assessment data has already shown that organisms differ widely in their ability to settle on a poisonous surface (Pyefinch[4]), and it is reasonable to expect that there will be a critical leaching rate above which settlement of a given organism will not take place.

In attempting to determine the critical leaching rates two methods are available ; assessments made on coated panels may be compared with leaching-rate determinations made on slides painted with the same compositions and exposed at the same time, or the leaching slides themselves may be assessed. In view of the difficulties of obtaining identical paint conditions on panels and on slides, and of providing identity of environment for the two exposures, the second method has been used in the present investigation. It is realized that the method chosen has disadvantages in that the fouling settling on a small painted slide may not be as typical as that which would occur on a larger painted area and that the surface used for assessment is being exposed at intervals to abnormal conditions, in particular, to the higher poison concentration during leaching. It is believed, however, that this method is more satisfactory if attention is particularly focused on the *first* appearance of organisms together with any subsequent increase, and if due allowance is made for aberrant results (arising, for example, from differences due to the position in which the slides are exposed on the raft).

The assessments are the mean ratings (0–7 basis) for the replicate slides (2 or 3) exposed. Where the mean rating exceeds 1 the paint is considered fouled (indicated by ● in the Figures) ; where this is less than 1 the paint is considered as bearing a trace (indicated by ◐ in the Figures) ; when clean, the symbol ○ is used.

" Brown Mats "

This algal growth which, due to its distinctive appearance has been termed " brown mats," is a prominent feature of the fouling settlement on the raft-exposed panels at Millport. The identity of the constituent weed or weeds is still uncertain (for a fuller discussion of this point *see* Pyefinch[4]), but from the practical point of view of assessing raft-exposed panels the constancy of their occurrence and the important part they play in the fouling sequence make it essential that their critical leaching rate should be known.

Figure 1 gives a plot of the leaching rate of a series of compositions against the presence of these growths, the assessments being made from early in August to mid-September. It is clear that few of these compositions, at 91 days (Fig. 1 *a*), were leaching at a sufficiently high rate to prevent settlement of this type of fouling, and the results obtained suggest that a leaching rate of the order of 20–25 μg./sq. cm./day is necessary to be certain of preventing their appearance. With one exception (258) all the compositions bearing traces of brown mats at 91 days had a significant rating at the next inspection 20 days later, when their leaching rates had fallen considerably (Fig. 1 *b*). From the point of view of this type of work these compositions were not ideal, since their leaching rates did not maintain steady values. At 132 days (Fig. 1 *c*), although none of the compositions were affording protection, eight had leaching rates of over 10 μg./sq. cm./day.

A second series, assessed only in the later stages

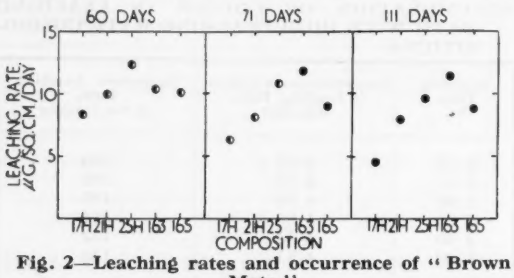

Fig. 2—Leaching rates and occurrence of " Brown Mats "

Table V
RATE OF " BROWN MAT " SPREAD

Composition No.	Mean " Brown Mat " Ratings after Exposure					
	30 days	44 days	61 days	77 days	97 days	123 days
277	0	0	0	1·0	2·0	3·0
281	0	0	Tr	1·0	2·5	2·5
282	0	0	0	1·5	3·0	4·0
284	0	0	Tr	2·5	4·0	5·0
285	0	2·0	2·0	3·5	4·0	5·0
293	0	0·5	0·5	1·0	1·0	1·0
307	0	0	0	2·0	3·5	5·0
313	0	0	0	Tr (?)	1·5	3·0
317	0	0	0·5	2·0	3·0	4·5

of its exposure (*see* Fig. 2), shows the same general relationships. At 60 days all the compositions had traces of brown mats and their leaching rates lay from 8–14 μg./sq. cm./day. Between this date and that of the final assessment at 111 days, no gross variations in the leaching rate took place and the traces of fouling of the earlier assessments gradually increased to significant values.

If the leaching rate of a composition under test stays between 10 and 20 μg./sq. cm./day for an extended period, then the settlement of brown mats is possible and usual; once settled they spread slowly over the exposed paint surface. Table V, based on a series of compositions with leaching rates within this range, gives an indication of their rate of spread.

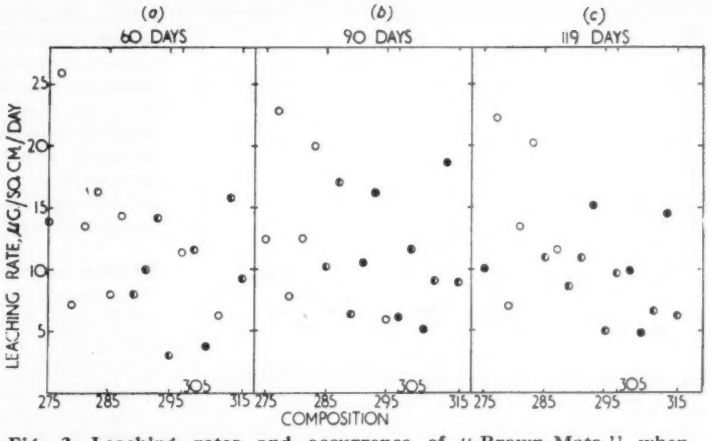

Fig. 3—Leaching rates and occurrence of "Brown Mats" when exposed on lower bar of exposure frame

Data from several other series of compositions substantiates the view that a leaching rate of 20–25 μg./sq. cm./day is essential to prevent the settlement of this "organism" on paints containing cuprous oxide as the only poison.

Since brown mats spread slowly they are unable successfully to compete against a more aggressive fouling organism which would settle on a composition with a lower initial leaching rate. Brown mats do not, therefore, become very evident under such circumstances. For example, paint 295 had leaching rates of 3·1 and 5·8 μg./sq. cm./day at 60 and 80 days, respectively. On the first occasion the fouling was rated as: *Obelia*, 2·5; *Pomatoceros*, tr.; brown mats, tr. At the second assessment the fouling was: *Obelia*, 3·5 and *Pomatoceros*, tr.

As has been previously emphasized, a heavy settlement of brown mats will effectively prevent settlement of most other types of fouling so that, subsequently, the time at which the leaching rate falls below the value of 10 μg./sq. cm./day cannot be determined in raft assessments; for example, all the paints in Table V, with the exception of 293 and 313, had leaching rates which towards the end of their exposure must have fallen below this value, but they continued to show only brown-mat fouling. It has been suggested that this type of settlement is not a peculiarity of the Millport site, so this difficulty is one which is likely to occur at other exposure stations and to vitiate determinations of length of anti-fouling life of raft-exposed compositions.

This brown-mat fouling is particularly characteristic of copper-containing compositions; these growths have not been observed on copper–mercury compositions. This can be illustrated by reference to data given in Table VI. This Table gives copper leaching rates and assessment data for a series of compositions, each pair of which is identical except for the replacement of 4% of the iron oxide filler by 4% of mercuric oxide in one member of the pair. In no case were brown mats found on mercuric-oxide-containing compositions even though the copper leaching rates of these latter were in many cases lower than those for the corresponding non-mercurial compositions as, for example, is particularly well illustrated in paints 198 and 201.

The sensitivity of brown mats to mercury and their comparative resistance to copper, explains the difference in the type of fouling previously emphasized as occurring between copper-containing compositions and copper–mercury containing compositions.

The exposures on which the above observations were made were at a mean depth of 2½ ft. (on the

Table VI

OCCURRENCE OF "BROWN MATS" ON COPPER AND COPPER-MERCURY COMPOSITIONS

Composition No.	Poison Content, %		Copper Leaching Rates, μg./sq. cm./day		Mean "Brown Mat" Ratings	
	Cu_2O	HgO	63 days	100 days	63 days	100 days
151	40	...	11·3	6·6	2·0	2·0
194	40	4	5·3	10·5	0	0
153	25	...	8·6	6·8	2·0	3·5
195	25	4	8·8	7·0	0	0
154	30	...	5·9	6·9	3·0	4·0
196	30	4	5·2	7·0	0	0
158	25	...	8·1	7·8	0	Tr
197	25	4	7·4	5·8	0	0
159	30	...	8·7	12·0	0	1·0
198	30	4	5·2	6·4	0	0
163	25	...	10·1	9·3	3·0	3·5
199	25	4	5·5	6·4	0	0
168	25	...	9·9	13·6	2·5	3·0
201	25	4	12·8	7·2	0	0

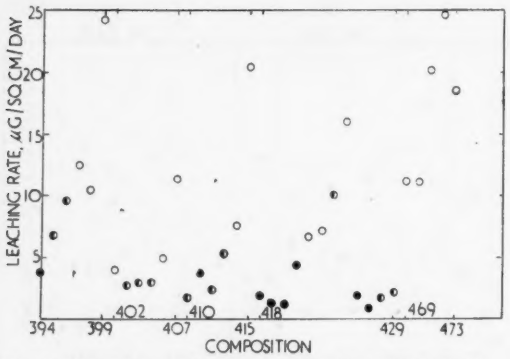

Fig. 4—Leaching rate and occurrence of *Tubularia coronata*

upper bar of a standard exposure frame), and under these conditions the correlation between leaching rate and fouling is well defined. However, if the conditions are altered by increasing the depth of exposure, *e.g.*, to 4 ft. (by exposure on the lower bar of the frame), the results are then more variable. This may be illustrated by reference to another series of compositions exposed at the lower level (Fig. 3).

Here it is evident that if throughout the three assessments the leaching rate is below the critical value, settlement does not necessarily take place at once, although compositions with leaching rates above this value remain clean as before. Thus, at the first assessment after 60 days' exposure, 50% of the paints with leaching rates between 5 and 20 μg./sq. cm./day were clean whilst the remainder bore traces of brown mats. The results of assessments at 80 and 119 days (Fig. 3 *b* and *c*) show that there is a gradual settlement and spread of this type of fouling, resulting in only eight paints within this group remaining clean at the end of these times. During this latter period there is no correspondence between leaching rate and incidence or rate of spread of fouling ; *e.g.*, 279 with a leaching rate of 8 μg./sq. cm./day was clean throughout, while 293 became fouled although its leaching rate remained in the neighbourhood of 15 μg./sq. cm./day. This suggests that compositions

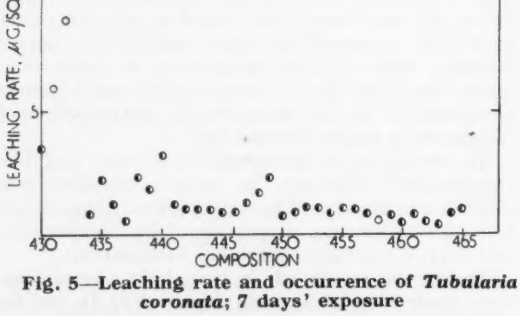

Fig. 5—Leaching rate and occurrence of *Tubularia coronata*; 7 days' exposure

with leaching rates within this range will eventually become fouled with brown mats provided that exposure is sufficiently prolonged, a suggestion amply substantiated by general assessment experience. It is not easy to suggest any one factor which is responsible for this phenomenon, but decrease in light intensity with its undoubted effect on physiological processes, particularly in relation to sensitivity to poisons and growth, is perhaps the most important factor concerned.

Tubularia coronata

Analysis of assessment data by Pyefinch[4] has indicated that *Tubularia* is among the most resistant animal fouling organisms ; if sources of local infection are sufficiently abundant *Tubularia* can be a severe test of the anti-fouling properties of a composition.

Figure 4 shows a plot of the occurrence of *Tubularia* against leaching rate for selected members of a series

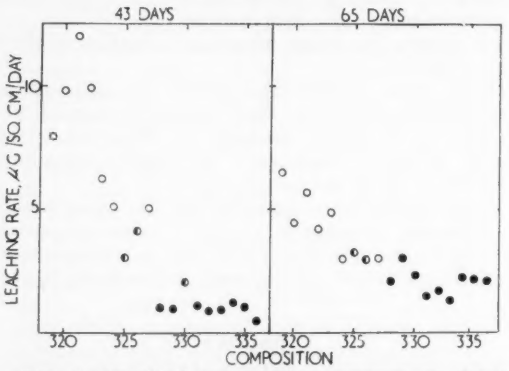

Fig. 6—Leaching rate and occurrence of *Obelia longissima*

of compositions after 21 days' exposure (the compositions omitted all had very high leaching rates, greater than 30 μg./sq. cm./day). It is clear that a leaching rate of the order of 10 μg./sq. cm./day is necessary to prevent settlement of this hydroid, although a small number of compositions with leaching rates below this value were not colonized, again possibly a result of environmental factors.

That *Tubularia* can settle very rapidly when conditions are favourable is indicated by the assessments of a series made within 7 days of exposure. These are shown in Fig. 5, from which it will be seen that almost all of these compositions had low leaching rates so that, with very few exceptions, the compositions were fouled with *Tubularia*.

Obelia longissima

Obelia longissima is the other hydroid commonly found on raft-exposed panels at Millport. It settles rather earlier in the summer (June and July) than *Tubularia* and analyses of assessments have indicated it to be much more sensitive to poisons than the latter genus, a deduction which has been fully confirmed by the present study. Figure 6 shows leaching rate and occurrence of *Obelia* after 43 and 65 days' immersion, from which it is evident that a leaching

rate of 4 μg./sq. cm./day is adequate to prevent fouling by this organism.

Pomatoceros triqueter

Pomatoceros is very sensitive to poisons and its occurrence on an exposed surface has been taken to indicate very inadequate performance. That this is true is clear from Fig. 7 from which a leaching rate of 3·0–3·5 μg./sq. cm./day is seen to be sufficient to prevent settlement. The critical leaching rate has been defined as that leaching rate which will prevent *settlement* of any particular fouling organism, so that the important factor is, therefore, the leaching rate at this time. Little is known of the relationship between leaching rate and growth of a settled organism, but that growth can take place above the critical leaching rate is indicated by the data given in Fig. 8. Compositions 294, 296 and 299 had leaching rates of 5·8, 4·8 and 5·5 μg./sq. cm./day respectively, at

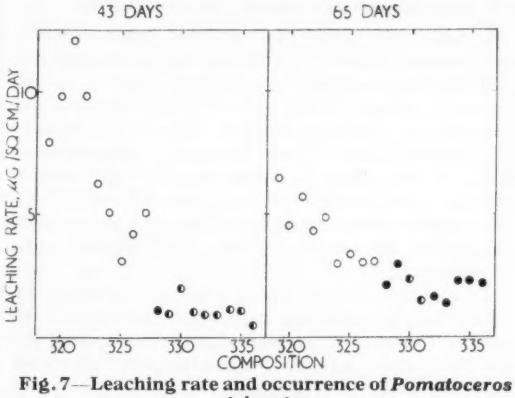

Fig. 7—Leaching rate and occurrence of *Pomatoceros triqueter*

80 days' immersion and were assessed as fouled with *Pomatoceros* in apparent contradiction to the above critical leaching figure. However, the leaching rates of all these compositions were showing a slow but steady rise, *e.g.*, 294 had the following leaching rates :

	Leaching Rate, μg. /sq. cm./day
3 days	1·7
10 ,, ...	1·5
21 ,, ...	2·6
42 ,, ...	3·4
60 ,, ...	4·9
90 ,, ...	5·9

and settlement of *Pomatoceros* had undoubtedly occurred early in the period of immersion. The subsequent rise in leaching rate did not prevent growth of the settled worms.

Other Fouling Organisms

The foregoing constitute the common fouling organisms which have occurred on painted slides exposed during the latter half of the fouling season of 1945. Comparing these fouling organisms with those listed previously there are three important omissions, *Enteromorpha*, *Ectocarpus* and *Balanus*. *Enteromorpha* has not been seen on these series of slides, and at the depth at which they were immersed

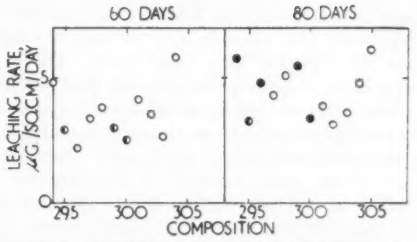

Fig. 8—Leaching rate and occurrence of *Pomatoceros triqueter* ; growth has occurred at a leaching rate higher than the critical

(a minimum of 2 ft.) this weed only rarely occurs in any quantity on a toxic surface. *Ectocarpus* has been recorded from time to time but its complex interrelationships with the structures termed brown mats make it difficult to define its own individual critical leaching rate. Recognizable *Ectocarpus* settlement has been recorded on compositions with leaching rates up to 10 μg./sq. cm./day. Most of the data represented here have been for exposures made when barnacle larvæ were not available for settlement, but one series exposed earlier in the year has given some information. Settlement and metamorphosis can take place in conditions too poisonous for subsequent development, but barnacles were found to persist on surfaces having a leaching rate below 9 μg./sq. cm./day. As occasion has offered, observations have also been made on the occurrence of the more sensitive fouling organisms on exposures of this type ; thus, for example, the critical leaching rate for *Didemnum* appears to be of the order of 2 μg./sq. cm./day. The results are summarized in diagrammatic form in Fig. 9.

The above data clearly indicate that the leaching rate test can be confidently used to indicate the behaviour of anti-fouling compositions ; the leaching rate at any given time is directly related to its capacity to prevent settlement of fouling organisms. The relationship so far established may be termed an overall relationship under the seasonal and exposure conditions existing in these investigations. It is not suggested that a single value of rate of loss will eventually be found which sufficiently characterizes the behaviour of any organism towards anti-fouling compositions : rather, it might be expected that a range of values controlled by a complex of factors will be found to determine the limits of settlement. Indeed,

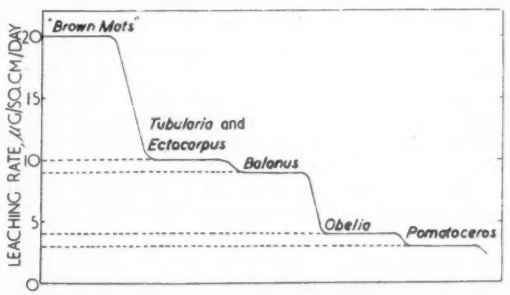

Fig. 9—Diagrammatic representation of critical leaching rates

as already pointed out, the leaching rate as measured must represent the average rate of loss throughout the whole of a period of a tidal cycle. There is an increasing body of evidence suggesting that settlement takes place only at slack or relatively slack water (*see*, for example, Smith[5]), so that the leaching rate is then to be considered only as a property characterizing the state of the paint surface at a particular time, but it will bear a fixed relationship to the rate of loss actually concerned in preventing settlement.

It is perhaps worth noting that if certain algal forms are considered as fouling, the frequently accepted critical leaching rate of 10 μg./sq. cm./day is clearly inadequate, although it has been found sufficient to prevent the settlement of all animal forms.

The limits have, then, been defined under circumstances which may be considered as representative of general exposure conditions in which settlement can take place. It is to be noted that the results agree in general with the order of sensitivity obtained from raft assessments (*see* Pyefinch,[4] also Weiss[6]). The American workers (Ketchum *et alia*[3]) found that a leaching rate of 10 μg./sq. cm./day was sufficient to prevent the attachment of all organisms except bacteria and some (unnamed) algæ ; the results here given support this contention. However, the constant occurrence of brown mats (whether considered as fouling or not) on cuprous oxide compositions exposed on the Millport raft make their consideration essential in making practical assessments.

THE LOSS OF COPPER UNDER SERVICE CONDITIONS

In order to investigate the loss of copper under service conditions the general procedure has been to take a number of 1-in. sq. samples of the paint from the ship after service and analyse them for copper content. From the original weight per unit area and the copper content of the composition the mean rate of loss over the period of service can then be calculated. There is a large number of possible sources of experimental error ; thus, if painting has been over a previous undercoat, then should any of this (which is very likely to contain copper compounds) be included in the sample, the rate of loss obtained will have a negative error. Such difficulties have, in part, been overcome by first painting a square foot of yellow anti-corrosive (AC 244) over the area from which the samples are to be taken and then applying the experimental anti-fouling composition. This has not, however, entirely eliminated the trouble ; much depends on the state of the paint and the relative adhesion of the several coats. For example, in one test the adhesion of the anti-fouling to the yellow undercoat was poor but that of the yellow to the lower coats extraordinarily good, so that in sampling, the yellow coat and the undercoats came away and the samples were useless. It should be remembered that samples are taken whilst standing on a ladder or staging under variable and often adverse conditions, and that it is desirable to remove flakes of paint rather than a powdery scrape. When to this are added all the vagaries of outdoor work, discrimination must be used and some samples rejected. Further, it is not possible to paint the leaching slides under conditions which reproduce exactly those existing during the ship painting. An overall accuracy of 10% or even 20% in the rates of loss of copper calculated from data so obtained is all that can be expected. Bearing these factors in mind the results do indicate certain points of considerable interest and importance. For comparison with raft performance, control specimens either as plates or painted slides were exposed and used for leaching-rate determinations as well as analyses.

The results so obtained may be illustrated by a consideration, in some detail, of the data obtained from a number of representative service tests ; the varying conditions and compositions used make it desirable to consider each of the tests separately. The service tests to be discussed have already been considered from the point of view of the assessment of anti-fouling performance of the compositions (Barnes, Bishop and Pyefinch[7]).

S.S. *Marchioness of Graham*, Service Test 4F

In this test three experimental compositions as well as one proprietary composition were employed ; 53H and the proprietary contained cuprous oxide as the only poison ; 193H and AF 1043 contained both cuprous and mercuric oxides. The vessel is one of the former L.M.S. Clyde Steamers ; approximately 50% of her time is spent under way, and the average speed of the vessel is of the order of 15 knots. The results of the analyses of the samples taken at the end of the service period of 147 days are given in Table VII.

In the case of the experimental composition 53H, which had a spreading rate approximating to that usually found in large-scale dockyard painting practice, the poison was for the greater part exhausted in only five months of service.

Analysis of the copper content of paint from panels exposed on the raft gave the following rate of loss of copper :

Composition	Rate of Loss, μg./sq. cm./day
53H	7·1
193H	7·0
AF 1043	2·1

The rate of loss on the ship was far greater than on the raft-exposed panels. The mean rate over the service period was approximately twice the mean rate of loss on the raft over the same period.

S.S. *Bellerophon*, Service Test 5F

The test was designed to compare the performance of the above experimental compositions when in service under tropical conditions. Two different proprietary compositions were used : No. 1 contained 19·6% of cuprous oxide and no other poison, whilst

Table VII

EXPERIMENTAL DETAILS OF SERVICE TEST 4F

Composition No.	Cu_2O Content of Wet Paint, %	Weight per Unit Area, g./sq. m.	Mean Rate of Loss of Copper, μg./sq.cm./day	Copper Lost, %
53H	17·2	195	14·8	73
193H	17·0	235	11·7	49
AF 1043	16·0	366	9·4	27

No. 2, also with 19·6% of cuprous oxide, had in addition large quantities of mercury compounds. The same batches of experimental compositions were used but the test was started some 50 days later, so that ageing of the paints may have taken place, a possibility substantiated by the thickening and consequent greater weight per unit area. (The paint tins had not been opened since the previous test.) The test lasted for 167 days, 85 in harbour and 82 under way, both periods including tropical conditions : the results of the analyses are shown in Table VIII.

Fresh raft exposures were not made, except for the two proprietary compositions, with the following results :

Composition	Mean Rate of Copper Loss, μg./sq. cm./day
Proprietary No. 1	9·0
Proprietary No. 2	18·5

Since the three experimental compositions had aged considerably, comparison with the raft figures for the previous test was not possible, but the rate of loss had fallen considerably in these aged compositions. The data for proprietary No. 1 indicate, as would be expected in view of the higher temperatures on the voyage, a still higher rate of loss compared with the raft losses. However, proprietary No. 2 has for this ratio the same value of 2/1 as was found in the previous test, in spite of the exposure to tropical conditions. This may mean that the temperature coefficient of the leaching process varies with the type of composition, for proprietary No. 2 was an unusual composition containing very large quantities of mercury compounds.

In the next four service tests to be considered the two compositions used were 23H and 28H, selected from earlier extensive tests. Composition 23H has 18% of cuprous oxide and 4% of mercuric oxide, and 28H, 24% of cuprous oxide and 6% of mercuric oxide, both in the same rosin–Bedesol varnish. Only the loss of copper will be considered.

S.S. *Marchioness of Graham*, Service Test 7F

The test was carried out during the winter months, October to February, the total period of service being 133 days, during half of which the vessel was berthed. Only the sample from the 28H test area was reliable.

Composition No.	Weight per Unit Area, g./sq. m.	Mean Rate of Copper Loss, μg./sq. cm./day	Copper Lost, %
28H	220	15·0	57

Exposures on the raft, made at about this time, gave 5·6 μg./sq. cm./day for the rate of loss of copper from 28H, but the paint had aged a little when the raft exposures were put out, with a probable reduction in the rate of loss which may account for the high ratio of the two losses.

Table VIII

EXPERIMENTAL DETAILS OF SERVICE TEST 5F

Composition No.	Cu_2O Content of Wet Paint, %	Weight per Unit Area, g./sq. m.	Mean Rate of Copper Loss, μg./sq. cm./day	Copper Lost, %
53H	17·2	263	7·7	32
193H	17·0	418	3·4	9
AF 1043	16·0	314	4·4	16·5
Proprietary No. 1	19·6	342	32·0	90
Proprietary No. 2	19·6	717	37·0	50

S.S. *Marchioness of Graham*, Service Test 10F

This test, extending only from February to May, lasted 70 days. The data obtained were as follows :

Composition No.	Weight per Unit Area, g./sq. m.	Mean Rate of Copper Loss, μg./sq. cm./day	Copper Lost, %
23H	79	10·5	58
28H	101	13·3	43

Samples exposed on the raft at about this time gave a rate of copper loss of 4·7 and 6·0 (mean 5·4) μg./sq. cm./day for 23H, and 5·6 μg./sq. cm./day for 28H. As before, the mean rate of loss on service is approximately double that found for raft-exposed panels.

M.V. *British Might*, Service Test 12F

The compositions in question had now been stored some five months with resultant ageing which would almost certainly have reduced the leaching rates. In this test the vessel was in the fitting-out basin for 69 days and when on service spent 135 days at sea and 45 in port : in this case again, therefore, the ship was in motion half the period of the test. The service was on the North Atlantic for the most part.

This was a new vessel so that no difficulties should have arisen from contamination with previous undercoats. The mean results of analyses of several samples gave the following rates of loss of copper from the compositions :

Composition No.	Weight per Unit Area, g./sq. m.	Mean Rate of Copper Loss, μg./sq. cm./day	Copper Lost, %
23H	223	8·5	59
28H	162	5·1	37

In view of the age of these compositions when painted out, comparison with previous figures for copper losses from earlier raft exposures is not desirable and no material was available for the analysis of raft-exposed specimens over this period. Data for the raft rate of loss can, however, be estimated from the leaching data obtained on the stored composition using the figures previously given. The mean rate of loss calculated from the leaching data over a period of 120 days was 7·7 μg./sq. cm./day for 23H and 3·3 μg./sq. cm./day for 28H. Taking 1·2 as the ratio of leaching rate to actual rate of loss on the raft (*see* p. 177) the corresponding raft rates would therefore be 6·4 and 2·7 μg./sq. cm./day, respectively. The ratio of loss during service to raft loss is lower than that previously found in the case of 23H but of the same order for composition 28H.

S.S. *Empire Bromley*, Service Test 17F

This test, on a new vessel, was started about one month later than the previous test so that little further ageing of the compositions should have taken place. The vessel was in wet dock 32 days before service began and subsequently spent 230 days on service, during approximately half of which time she was in port. The weight per unit area for both compositions was 107 g./sq. m. (17·1 g./sq. m. of copper in 23H, 23 g./sq. m. of copper in 28H). The mean rate of loss on the raft for these compositions over an extended period has been shown to be 6·4

and 2·7 μg./sq. cm./day (*see* previous test). On the assumption previously given, 32 days at the raft rate and double the raft rate for the service period (half in port), the calculated total loss of copper would be 31·5 g./sq. m. for 23H. Clearly, the composition would be exhausted long before the end of the service period and the mean leaching rate as determined by analysis of the samples at the end of the period would therefore have little significance. The samples brought back for analysis had actually lost 95% of the contained copper. For 28H the copper loss so calculated should be 13·3 g./sq. m. In the analysis of the samples 9·3 g./sq. m. were found, *i.e.*, a loss of 13·7 g./sq. m., in good agreement with the calculated value.

S.S. *Marchioness of Graham*, Service Test 25F

This test, using a high cuprous oxide composition, 288, was only of 62 days duration, and was made during the winter period and under similar service conditions previously given for the vessel. When the samples were taken the paint was very dry and hard and undoubtedly most of the samples were unreliable. However, a small number of samples taken from under the bilge keel was considered reliable, and the rate of loss during service was found from these to be 36 μg./sq. cm./day. Raft panels were exposed at the same time and gave a rate of loss of 20 μg./sq. cm./day.

The rate of loss of poison in raft tests varies during the period of soaking and presumably this is true for the rate of loss in service. An attempt was made, therefore, to determine the relationship of the losses at short intervals. This involves sampling the composition during service and with this end in view small metal panels (4 × 3 in.) with a projecting lip at the lower edge and with a weighed quantity of the anti-fouling composition over the upper 3 × 3 in. were stuck on the hull when the ship was in dock. They were applied about 2 ft. below water-line; preliminary tests had shown that similar panels could be removed when in such a position by means of a specially designed tool. It was intended to remove panels at monthly intervals when the ship was berthed. Only one panel was successfully removed and that was situated near a condenser outflow. Several patches of this 3 × 3 in. plate were analysed and the results were in good agreement; the mean rate of loss was 102 μg./sq. cm./day. This is greatly in excess of the figure of 36 μg./sq. cm./day already given for the sample taken from the large patch: the discrepancy may be due to the turbulence when the ship is standing with the condenser discharge running (as is the case for several hours per day), and this may be enhanced by a slightly higher temperature in the neighbourhood of the condenser discharge. The results show that locally the rate of loss of poison may be considerably higher than the general rate over the hull as a whole.

S.S. *Duchess of Hamilton*, Service Test 19F

Only one satisfactory sample was taken of YC, a copper-soap composition containing a high proportion of cuprous oxide. The rate of loss on raft panels given by analysis was 27 μg./sq. cm./day and on the ship 36 μg./sq. cm./day. Out of a total of 71 days from the beginning of the test it was found that 44 had been spent in harbour before service and 7 days in harbour at the end of the test. On the basis of the previous results the expected mean rate of loss under such service conditions would have been 35 μg./sq. cm./day.

DISCUSSION

A consideration in detail of the bearing of these results on the calculation of possible raft and service performance from leaching rate data is postponed until these data have been presented. However, some general implications will now be discussed.

A composition will fail when the leaching rate drops below 10 μg./sq. cm./day, and it follows that the maximum anti-fouling life will be obtained by maintaining just this critical leaching rate throughout the exposure. In such an ideal composition the life will be directly proportional to the copper content and weight applied per unit area. Since the leaching rate measured under the standard conditions is 1·2 times the actual rate of loss,

$$\frac{1{\cdot}2 \times \text{Copper}\,(\%) \times \text{Weight/Area} \times 10^2}{10} = \text{life (days)},$$

where weight/area is in grammes per square metre.

Under service conditions similar to those described,

2 × Mean Raft Rate of Loss = Mean Rate on Service,

so that the service life is half the raft life.

Table IX gives a summary of the possible anti-fouling lives for varying weights per unit area and for a number of copper contents.

A copper content of 20% (Cu_2O 23%) is common amongst commercial anti-fouling compositions. At maximum efficiency and a weight/area of 150 g./sq. m. such a composition could have a raft life of about one year. To obtain one year's life in service the weight per unit area applied would have to be increased to 300 g./sq. m. Such a thick coat is rarely obtained with a composition of normal consistency; a more usual value is of the order of 150 g./sq. m. It is evident then, with paints which are normally applied at this weight per unit area, that it is essential to have a copper content of the order of 40% (Cu_2O 46%) for one year's service life.

It should be stressed that no change in formulation can affect these figures; they are the maximum possible lives.

A further point of some considerable interest regarding the practical testing of compositions is raised by the above data. It is frequently asserted that the severest test for a composition is exposure on a raft: such statements have their origin in the fact that since fouling only takes place when a vessel

Table IX

DETAILS OF WEIGHT/AREAS, COPPER CONTENT AND ANTI-FOULING LIFE

Wt. of Copper/Unit Area, g./sq. m.	Wet Weight of Composition at Various Copper Contents, g./sq. cm.			Life, days	
	20%	30%	40%	Raft	Service
10	50	33·3	25	120	60
20	100	66·6	50	240	120
30	150	99·9	75	360	180

is in harbour, and not when under way, constant immersion under raft (harbour) conditions gives a greater chance of fouling settlement. However, it has been shown that there is a greater loss of poison when the ship is under way than under harbour conditions, so that clearly the severest test is not that of constant raft conditions. The severest test would be for a composition to be applied before a long voyage followed by docking in port with a constant heavy potential fouling. If an imitation of such conditions could be introduced into anti-fouling testing it would be a considerable advance on the present techniques. Conditions could be adjusted, either by agitation of test plates or of the water, to imitate voyages of varying duration and speeds of varying amounts. The test plates could then be transferred to an ordinary raft during the fouling season and the merits under conditions approximating more closely to those of actual service be thereby elucidated.

SUMMARY

A discussion of the relationship of loss of copper from anti-fouling compositions under storage and exposure conditions is given. It is considered that the simplest method for a leaching-rate test is storage of the composition to be investigated in the sea.

For a number of compositions the ratio of the loss of copper from raft panels to the mean leaching rate determined by the method previously described, is of the order of 1·0/1·2.

A comparison is made between the leaching rate and anti-fouling behaviour of a number of compositions and it is established that a critical leaching rate exists for a given organism above which settlement of that organism will not take place. The critical leaching rates for a number of common fouling organisms have been determined.

The loss of copper from compositions in service has been determined and compared with loss from raft-exposed panels and leaching rate data of the same compositions. Under service conditions the loss of copper is greater than under raft exposure. The bearing of these facts on anti-fouling life is considered.

Acknowledgments

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The help given by Mr. C. A. Bremner, until recently Marine Superintendent of the former L.M.S. Railway Co., and by his successor, Mr. R. D. Kerr, should be particularly stressed.

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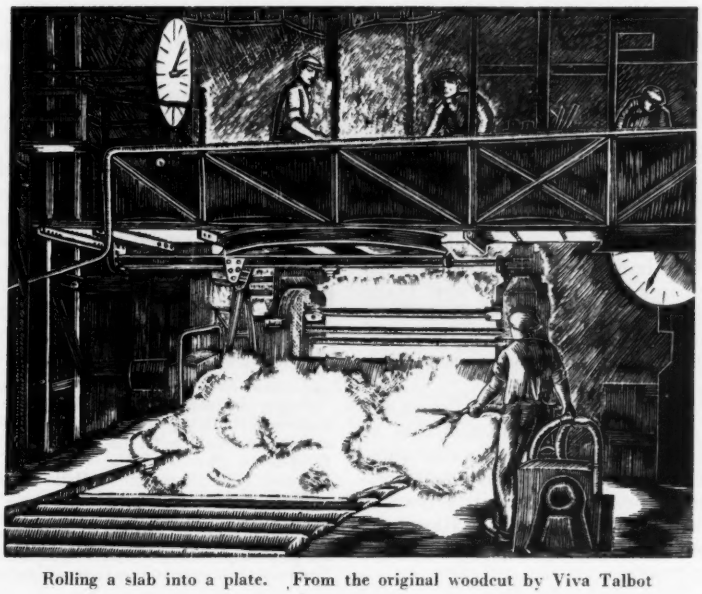

Rolling a slab into a plate. From the original woodcut by Viva Talbot

Trends in Pig-Iron Manufacture

By T. P. Colclough, C.B.E., D.Sc., and
I. S. Scott-Maxwell, A.M.I.E.E., A.M.I.Mech.E.

PIG-IRON PRODUCTION

EXAMINATION of production statistics over the last sixty years indicates that while the world production of pig iron has shown a general steady increase, the position of Britain has not been maintained (*see* Fig. 1). Up to the 1914–18 war the production in this country showed a progressive increase, but at a slower rate than the other main producers, and since 1920 pig-iron manufacture

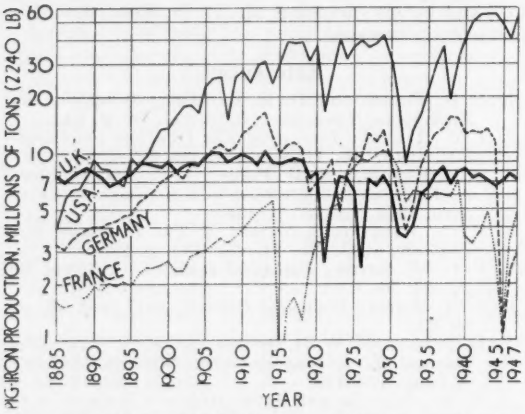

Fig. 1—Pig-iron production in principal producing countries from 1885 to 1947, on logarithmic scale

in Britain has been at a consistently lower average rate than in previous years. While in the twelve years up to 1920 the average production of all types of iron was over 9 million tons per year, production during the succeeding twelve years, 1921–1932, owing to unstable economic conditions and labour unrest, coupled with increased imports and out-of-date furnaces, fell to an average of less than 5·5 million tons per year, a fall of 40%.

The establishment of tariffs in 1933 led to an immediate improvement, and iron production rose progressively to a maximum of 8·5 million tons in 1938. Further increases during the war were made impossible by the loss of imported ores and by war-time conditions, and production for the years 1939–1946 averaged 7·5 million tons, as shown in Fig. 2.

This production is clearly inadequate to meet the needs of the country, and it is estimated that to satisfy the requirements of the present programme for steel and iron castings the pig-iron and ferro-alloys production must be raised within five years to 11·4 million tons which, with the normal allowances for operation, represents a required capacity of about 13 million tons per year.

The expansion of pig-iron production will not be distributed evenly over the different types of iron, but will be mainly required in furnaces producing basic iron for steelmaking. The increase in production of foundry iron will be of the order of about 1 million tons as compared with 1938, and very little change will be required in the capacity for hematite iron.

It will be accepted that an increase of this magnitude can be carried out only by a carefully arranged plan, as it is imperative that all installations, both for

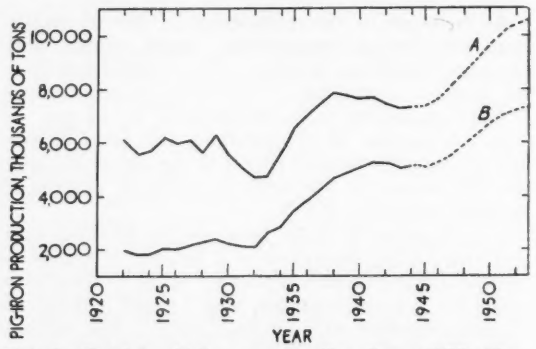

Fig. 2—British pig-iron production from 1920 (five-year moving average). Curve *A*, all types of iron; curve *B*, basic iron only

new capacity and the replacement of obsolete units, shall be in accordance with the most recent experience and the maximum possible economy.

INTEGRATION OF PLANTS

It has now been accepted that an increasing proportion of the steel-ingot production should be made by the hot-metal process and that practically the whole of the pig iron used for steelmaking should be made in blast-furnaces associated with these hot-metal plants. The advantages of integration in steelworks are too well established to require any elaboration, and it is now agreed that the same principles should be applied to the making of foundry irons. A large proportion of the foundry-iron capacity should be built in association with industries which are large consumers of the iron and can usefully employ the surplus gases from coke ovens and blast-furnaces.

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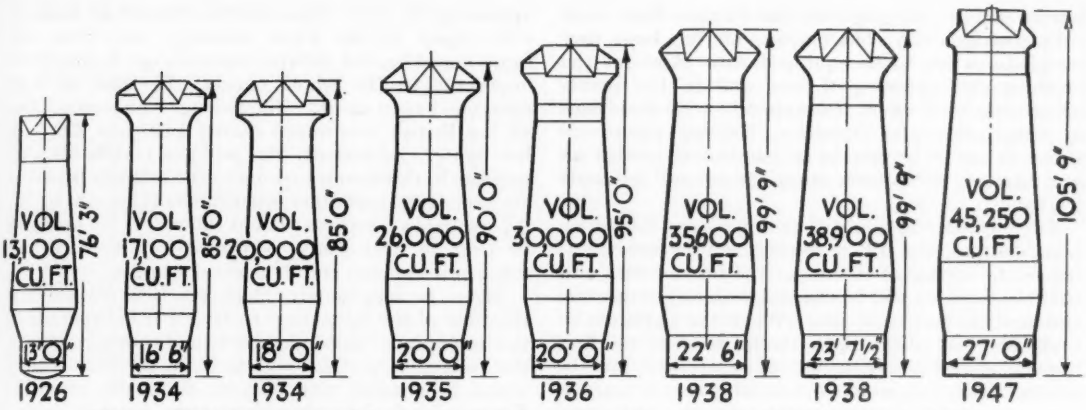

Fig. 3—Blast-furnace development in Britain and on the Continent between 1926 and 1947

SIZE OF FURNACES

The production of pig iron in the United States was practically doubled (22 million to 40 million tons) between 1905 and 1916, and this expansion was reflected in a marked increase in the capacity of the individual furnaces. This development was continued after the world war, until in the nineteen-twenties the standard capacity of furnace was of the order of 1000 tons per day, and today outputs of 1200 tons per day are not uncommon.

On the other hand, British production continued to be made in a large number of the small furnaces typical of the early part of the century, and even in 1920 furnaces producing 1000 tons per week on home-ore burdens were regarded as modern. The trade recession and unsettled conditions in the nineteen-twenties were not favourable for large expenditures on modern furnaces, and the opportunity was taken to demolish a considerable number of the small obsolete units. The revival of trade in 1933 marked the beginning of the movement to apply American experience to the modernization of the British furnaces. Throughout the last twelve years there has been a continuous development of larger units, complete mechanization, increased volume, and greater production. Each step in these directions has been justified by experience and has demonstrated that the principles are fully applicable to British conditions under both foreign- and home-ore burdens.

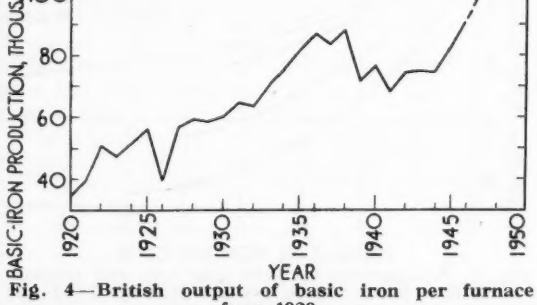

Fig. 4—British output of basic iron per furnace from 1920

The progress of this development is illustrated in Fig. 3, and it is accepted that the modern efficient unit must be in the range of 23–27 ft. hearth diameter and 40,000 cu. ft. effective volume, giving a productive capacity of 1000 tons per day on rich-ore burdens and 500–600 tons on home-ore burdens.

The latest proposals provide for the erection of furnaces of 27 ft. 6 in. hearth diameter and 45,000 cu. ft. volume, well in line with developments in any country.

The effect of the progress which has already been accomplished since 1933 can be demonstrated by consideration of various factors. The number of blast-furnaces installed has been reduced from 332 in 1933 to 157 in 1946, by the scrapping of many small units, but the average production per furnace in blast has increased from 1110 tons per week to over 1500 tons per week in 1946 (*see* Fig. 4). This production figure is far below the attainable economic level and must be raised to the order of 3000 tons per week. In 1946, only 15 furnaces were over 18 ft. hearth diameter, and there still remained 89 furnaces under 14 ft. hearth diameter. These small furnaces cannot be maintained, and it is planned to erect, within five or seven years, 24 new furnaces of over 20 ft. hearth diameter.

In the manufacture of foundry iron, furnaces of 18–22 ft. hearth diameter are proposed in order to maintain balanced production. This represents a marked advance in this branch of the industry. Production will be centred in four or five large units, which will be integrated with coke ovens and foundries for the local use of a high proportion of the iron made. Blast-furnace gas can be used for coke manufacture, and coke-oven gas for heating in the foundries or in chemical works, making possible the attainment of a high level of efficiency.

PREPARATION OF RAW MATERIALS

The experience gained in the operation of the larger furnaces has proved that the optimum results can be attained only by regular operation, and the claims made for the necessity of preparation of the

burden before charging into the furnace have been fully justified. In consequence, all the large new installations are to be equipped with plant for the crushing and screening of ores, and in the plants using home ores which are subject to wide variations in composition and character, bedding plants are either in use or in process of installation so that an ore mixture of uniform composition can be made available.

There can be no doubt that in the near future, on home-ore practice, all ore mixing will be carried out before the arrival of the ore at the furnace bins and that the furnaces will be charged with an ore mixture classified in ranges of size. What the optimum or maximum size of ore piece should be is of the first importance. Full efficiency of operation can be attained only when the descending ore mixture is thoroughly heated and reduced by the hot gases ascending in the furnace stack. The extent to which this can be accomplished in the time available is dependent upon the size and character of the ore, and technical examination of the various ores from this angle is urgently needed. Experimental work on this subject has been in progress for some time, but, owing to lack of facilities and manpower, results are not yet available.

Sinter

The crushing of ores inevitably increases the proportion of fines in the product, and here again experience has proved the necessity for screening-out the fines and for their agglomeration before charging back into the ore mixture. While the last twelve years have shown a marked increase in sintering capacity, it is to be regretted that there has been little or no improvement in quality, and it is common experience that the proportion of sinter which can be usefully incorporated in the burden is limited by its quality.

Sinter is of benefit mechanically in the furnace in that it increases permeability. Beyond a certain proportion, however, poor reducibility has an adverse effect. Improved quality at the moment is probably limited only by the engineering design of existing sinter plants. Insufficient flexibility is provided for preparing the raw materials; inaccurate feeding arrangements upset the sintering mixture; poor mixing and moisture control give an uneven product; correct deposition of the raw mix on the sinter machine is hampered by inherent faults in design giving rise to segregation; and most plants have poor draught control.

Experimental work is in hand to determine the factors governing the quality of the product and to secure improved methods of manufacture. Examination of German practice in this respect and of recent work carried out in this country indicate that the first steps to be taken lie in the direction of finer crushing of the ore and coke used and the securing of a uniform mixture for charging on the sintering strand. This in turn would appear to favour the more general adoption of the layer charger in place of the swinging spout, which depends for its action upon segregation of different sizes of material.

Upgrading of Ore

Another main problem yet to be solved is that of upgrading the ore. This question should be tackled with vigour by the whole industry, since iron ore forms one of our few natural resources and is therefore important to the whole nation. In time of war everyone has to use it. The average iron content for all the British ores mined during 1946 was 29%—a low figure. Admittedly the problem is difficult and peculiar to this country owing to the relation between the iron oxides and other constituents of the ore body. All available resources should, however, be brought to bear on this study, particularly in view of the rising price of coal and its general scarcity.

There is surprisingly little practical experience recorded of the advantage to be got from upgrading the iron units. Each operator can of course calculate the reduction in coke and increase in output that would be possible with his own particular practice. No empirical data, however, have been collected of the relationship between burden ratio, coke rate, and iron units charged. Such factors would be most helpful in assessing furnace performance.

A series of curves for American furnaces, taken from a recent paper by Old, Elmeida, Hyde, and Pepper,[1] is shown in Fig. 5. It would appear that for an increase of 8 units of iron in the burden a coke reduction of 10 or 11% is obtained. Furthermore, Joseph[2] indicates that with sized ore it is possible to burn almost 20% more coke per square foot of active hearth area. While these figures cannot be strictly applied to British-ore practice, it is obvious that with a rising coal price the amount of money available for the upgrading of ore as a result of saving coke becomes increasingly greater.

Foreign Ore

Imported ores do not require bedding plants, as the chemical analyses are reasonably constant. There are, however, wide differences in reducibility rates. Most of the imported ores received in Great Britain fall into three classes of reducibility. The problem here is therefore one of the correct sizing, and this can be solved much more easily. Experiments have been conducted in America[3] to show the relationship between the size of the ore piece and the reduction time. Similar experiments are being carried out in this country on the usual types of imported ore, as well as on British ores.

COKE MANUFACTURE AND GRADING

An outstanding feature of the developments in the

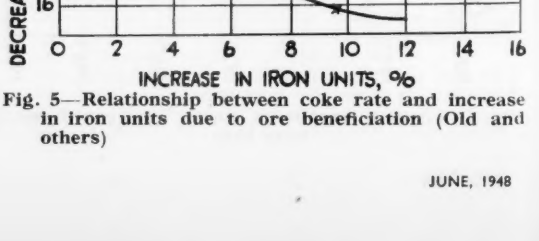

Fig. 5—Relationship between coke rate and increase in iron units due to ore beneficiation (Old and others)

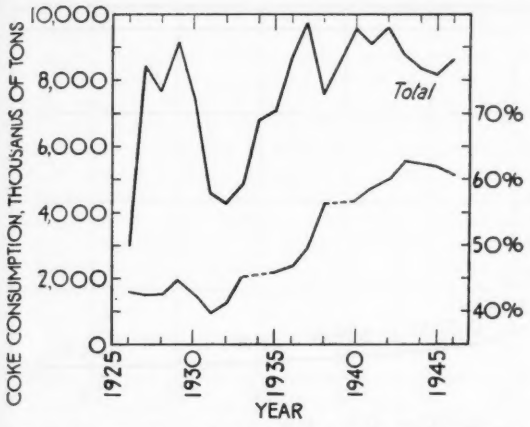

Fig. 6—Percentage of total coke made at integrated ovens

last fifteen years is the attention paid to the quality and sizing of the coke used. It has been demonstrated that coke breeze and fines below, say, 1-in. mesh are of little or no value in the blast-furnace. It is to be specially noted that the two works which show the best coke performance are equipped with special facilities for screening coke and are in a position to maintain high quality of coke by the use of suitable blends in their own coke ovens. Further, it is common experience that the coke rate in many places shows a marked increase as the quantity of coke purchased from outside sources increases. These facts indicate clearly the line of action to be followed.

The quality of coke which gives the best results is dependent to some degree upon the characteristics of the burden, and to secure the best conditions it is desirable that the making of the coke should be under the control of the ironmaker. This in fact is the present trend, as shown in Fig. 6. It is also common experience that in many cases the coal mined in individual pits cannot give the desired quality of coke and that coke of much higher quality can be made by a blend of coals from different sources. On these grounds there is a growing tendency for the coke ovens required to make blast-furnace coke to be installed as an integral part of the iron manufacture. In these installations special regard must be paid to the handling of the coke to prevent loss by breakage, and the coke should be finally screened at the entry to the furnace skip.

Quite apart from the chemical characteristics of the coke, which are mainly dependent on the coals used in the blend, the working of the blast-furnaces is largely controlled by the physical qualities of the coke, and of these the most important factor is the size grading.

The production of the furnace is dependent upon the rate at which the pieces of coke can be burnt at the tuyeres and upon the volume of air per minute which can be blown through the furnace. Since the coke, by volume, normally occupies about 60% of the furnace, both these factors are dependent upon the size ratio and the voids in the coke layers. A series of curves by Furnas[4] giving the relationship between these factors is shown in Fig. 7. The maximum percentage of voids and therefore minimum resistance to gas flow is attained when all the pieces are of the same size. The minimum permeability to gas flow is found when the bed consists of 65% of very large pieces mixed with 35% of very small pieces. Further, the actual resistance to gas flow increases as the disparity between the maximum and minimum sizes grows.

Joseph[2] has shown (*see* Fig. 8) that the resistance to gas flow begins to increase when the particle size falls below 1 in., and increases rapidly as the size falls below $\frac{1}{2}$ in.

It is also generally accepted that irregular working of the furnace and channelling, with their inefficient utilization of the ascending gas stream and resulting high coke rate, are due almost entirely to irregular distribution of the charge, which in turn results mainly from inequality of physical size in the pieces of ore and/or coke.

This accumulation of evidence and experience, is, to say the least, impressive. The grading of the blast-furnace materials can be carried out at relatively low cost, and it is the opinion of the present authors that greater improvements in output and lower coke consumptions can be more readily attained by the installation of equipment to give a burden of sized and graded materials than by any other proposals under recent discussion.

LAYER CHARGING BY SIZES

The conditions for maximum permeability to gas flow have already been outlined in the section on coke. Let us examine the conditions for maximum voids in relation to the earlier notes on ore preparation. At present all furnaces charge ore and coke in layers, but owing to the inherent difficulties of the present bell charging these layers show a wide variation of permeability in a section across the furnace. The periphery of the layers and the central core are occupied by a preponderance of large coke and larger pieces of ore, while the intermediate space is occupied by a densely packing mixture of fine ore and small coke. As a result the permeability of this intermediate zone is far less than that of the core and periphery, and the greater part of the gases passes either up the central column of the furnace or, to a lesser extent, up the surface of the brickwork, and

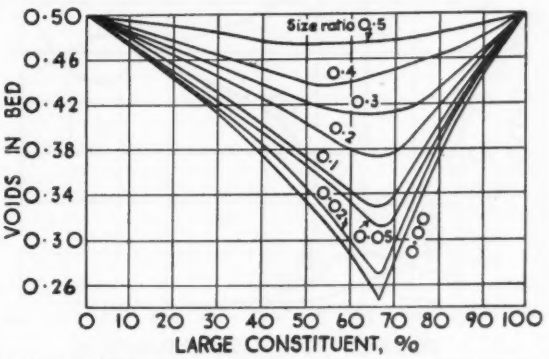

Fig. 7—Maximum reduction of voids and maximum size ratio in two-component systems (Furnas)

much of the finer sizes of ore reaches the bosh of the furnace in a relatively unheated and unreduced condition. On the other hand, the furnace gas rushing at high velocity through the zones of lower permeability escapes with a far higher proportion of unused carbon monoxide than is compatible with high efficiency. It is imperative, therefore, that a higher degree of uniformity as regards permeability be attained in each of the layers.

With British ores the problem of layer charging by sizes can be approached in a relatively simple manner. The ores can be crushed and bedded to give a uniform mixture. Then, immediately before charging, these should be screened, firstly to take out all the fines below ½-in. and secondly to split the remaining tonnage into two size groups, say, 3–1½ in. and 1½–½ in. These two sizes should be charged into the furnace separately. It has been demonstrated that material with a size ratio of 2 to 1 will, within practical limits, cause the minimum separation of sizes as the material falls into the furnace from the bell, and that this ratio will give a bed of maximum permeability. Further, since all the particles will be within a close range of size, the permeability across the whole layer will be relatively uniform. There will therefore be a far less tendency for concentration of gas flow in a limited area of the cross-section.

In the case of foreign ores the problem does not offer so ready a solution, as these ores differ widely in their reducibility. With hard dense ores of the Kiruna type the maximum size of ore piece will be far smaller than in the case of an easily reducible ore like Ouenza.

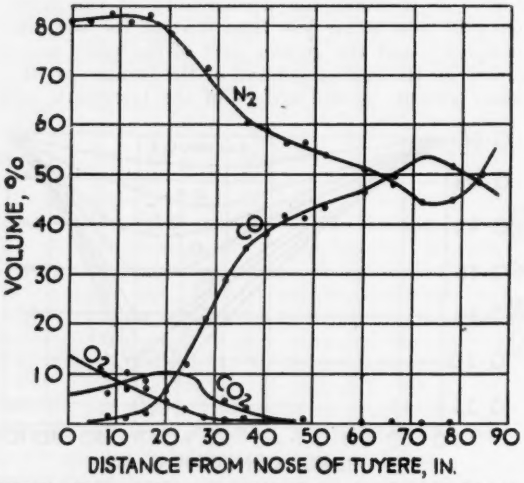

Fig. 9—Tuyere-gas analysis. Average of results from thirteen furnaces (Kinney and others)

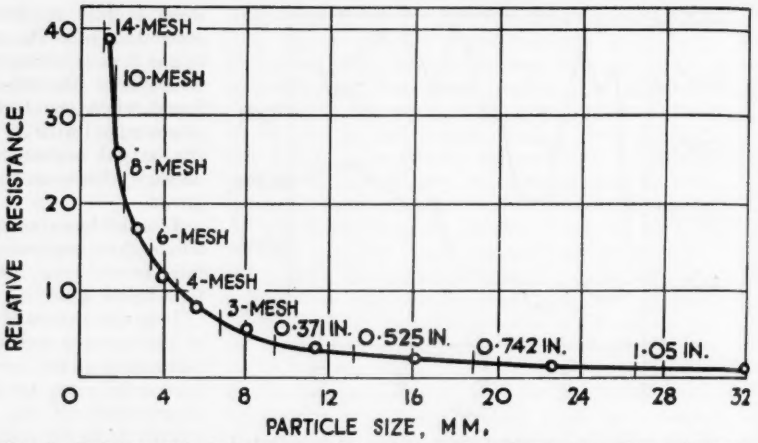

Fig. 8—Relationship between particle size and resistance to flow of gases. The resistance to the gas flow varies inversely as the 1·2 power of the average particle diameter (Joseph)

In such circumstances it may not be possible to maintain the ore fractions within the size ratio of 2 to 1, and in any event the two size groups would contain different proportions of each of the constituent ores. It will probably be found highly desirable to have not more than two different types of ore in the burden, and these should not be of widely different characteristics. The maximum outputs and lowest fuel consumptions will tend to be obtained with ores of only one type in the furnace, and the arrangements made for the distribution of foreign-ore supplies to the individual works in this country should be made with special regard to this feature.

FURNACE SIZE AND EFFICIENCY

As stated earlier in the present paper, the new furnaces to be erected will be of considerably greater capacity than the existing normal type. Furnaces with large hearth diameters, say over 20 ft., are necessary if the large outputs required are to be attained. It is, however, questionable whether the increase in stack height is either necessary or desirable if suitable operating conditions are established.

With regard to the hearth area, it must be recognized that the amount of coke which can be burnt per square foot of actual hearth area decreases as the furnace size increases. It has been demonstrated[5] (*see* Fig. 9) that the oxygen content of the air blown is exhausted at a distance of 50 in. from the nose of the tuyere, thus showing that there is a large central inactive core in the bosh area. By assuming a 6-ft. active annulus, Joseph,[2] using empirical data from a number of American furnaces, shows that this figure gives a coke consumption which is proportional to the area of this annulus. The area of this effective annulus is 6π $(D - 6)$, where D is the hearth diameter. On this basis the area of the inactive core on a 20-ft. dia. furnace is 50 sq. ft., compared with 133 sq. ft. for a 25-ft. furnace.

Joseph calculates that the capacity of American furnaces on this basis can be rated at 3·6 lb. of coke per minute per square foot of active annulus when operating on average raw materials, and at 4·2 lb.

of coke per minute when charged with beneficiated materials. A preliminary survey of a number of British furnaces—which could be extended with benefit—gives corresponding figures of 2·75 lb. of coke per minute on home-ore practice, and 3·0 lb. of coke per minute on foreign-ore burdens. It is to be noted that the British figures are lower than those for American practice, indicating that the British furnaces are not driven to anything like the same extent as in America. It would appear that, given correct conditions, British furnaces should be capable of being driven at some 30% higher rate than in present practice, and this factor should be investigated.

The limiting factor in American practice would appear to be the loss of ore as flue dust, which is obviously related to the gas velocity in the throat. With increasing volume of air blast these throat velocities must rise and, so long as the raw materials are distributed unevenly across the section of the furnace, high flue-dust losses must result. Kinney[6] states for experiments at Cleveland that, whereas the actual voids at the furnace-throat level were about 40%, the effective voids for the passage of gas were only 10% of the total area—amazingly low. Under these conditions it is obvious that the gas velocities are too great for an effective intercharge of heat between gas and burden and for the reduction of the ore by the ascending gases. In order to overcome this inefficiency the tendency has been for furnaces to be built to greater and greater heights. If, however, the furnaces are correctly charged so as to give uniform distribution of the materials, the more uniform permeability of the burden will provide greater void areas, decrease the velocity of the ascending gases, and give a more effective heat transfer from gas to raw material, and it may well be that instead of a greater stack height being necessary it will be found that a lower stack height will be more efficient.

FUTURE TRENDS

Future trends clearly cannot be defined, but sufficient work has already been done to indicate possible developments in three distinct directions. All three are based on the overriding problem of increased production, with its concomitant lower coke consumption, and all aim at securing the improvement by attaining a more efficient use of the coke charged by reducing the velocities of the ascending gases in the shaft of the furnace.

Compensated Charging

The first of these improvements is the development of the compensated charging device by Saunders and his colleagues at the Imperial College, South Kensington. From his well-known classic studies[7] on the maldistribution of charges and the effect of variations of material size and density upon the distribution and packing of the material in the blast-furnace shaft, which are inherent in the present method of charging by the use of a bell and hopper, Saunders has evolved an improved method of charging. By this device it is hoped that the furnace operator will be able to exercise a measure of control over the radial distribution of the material on the stockline and to secure any desired type of stock-line—either **M** or **V**—by depositing material either towards the walls or the centre of the stack at will. Given raw materials which have been sufficiently prepared to give a reasonably close size grading, the improvement of distribution which should be attained must give some advantage.

As discussed earlier, it would appear obvious that the elimination of the zones of loose packing in the central core and on the walls would give a more uniform gas flow through the mass of the burden and prevent the formation of the localized high-velocity gas streams which create high flue-dust losses and lower efficiency by virtue of the little or no ore reduction which they carry out. The more uniform packing will probably cause an increase of resistance to gas flow in the furnace stack, and higher blowing pressures may be necessary, but the more uniform gas penetration, with its higher efficiency, will reduce the volume of air required per ton of burden. These two factors may be utilized in two different ways, depending upon the characteristics of the blowers. Either the existing production can be maintained by blowing a smaller volume of wind at its higher pressure or, as is normally possible, the production of the furnace will be increased by blowing the existing volume of wind at the required higher pressure.

A suitable design for the full-scale operation of this compensating device has not yet been developed, and, while certain engineering difficulties are to be anticipated, it is suggested that operators should give urgent consideration to this possible solution of many blast-furnace troubles.

High-Top-Pressure Operation

The urge for increased production in America has led to the blowing of increased volumes of wind and to increased volume of furnaces, but, since there has been no improvement in design or distribution, a limit has apparently now been reached at which the economies attained by increased size of hearth are more than neutralized by the increased loss in flue dust and efficiency. It is now suggested[8] that these losses can be overcome by the operation of the furnace under higher pressures by creating a back pressure on the gas exit from the furnace. The theory underlying this proposal is well known and generally accepted. The losses arise from the exceedingly high velocity of the gases passing through the stock column; any increase of the volume of air blown per minute must increase the velocity. On the other hand, the volume of gases varies inversely with the pressure, and therefore any increase of pressure will decrease the volume and the velocity of the gases and thereby reduce the flue-dust losses. It is further claimed that if the velocity of the gases is reduced there will be an increase in the time available for interchange of heat between gases and burden, and greater opportunity for the reduction of the ore by the ascending gases, both factors tending towards more efficient use of the coke. The experimental work carried out in America on full-scale modern furnaces has demonstrated that these theoretical considerations do apply in practice, but the extent to which they can be utilized economically still remains to be determined.

The tests have shown that with higher pressures

within the furnace the rate of blowing and the daily production of iron can be increased substantially, or, alternatively, if the rate of blowing is increased to only a small degree a reduction of coke rate can be made. The economics of this modified operation are still in need of clarification, and the extent to which the development can be applied to British conditions demands careful consideration.

The modification of the blast-furnace and its ancillaries to permit the use of higher pressures presents quite a number of engineering problems as yet unsolved and also involves considerable capital expenditure. The problem in the United States differs from that in Britain. The American ores are well mixed and fairly uniform in composition at the point of delivery to the blast-furnace, but suffer from a large proportion of fines. The removal of these pieces for sintering would present a problem of considerable magnitude owing to the volume of material below ½-in. mesh to be handled, and it may well be that the cost of high-top-pressure operation may prove less than that of installing and operating the high-capacity sinter plants required. The problem in Britain, especially with furnaces operating on home-ore burdens, is that of handling ore which is too large for furnace use, and efficient preparation is the first essential. If high-top-pressure operation were adopted in Britain, ore preparation would still be necessary, and it is suggested that the use of high-top pressures can be regarded as only a secondary and not as a primary measure, since it does not deal with the basic problem of incorrect distribution.

Oxygen-Enrichment of Blast

The use of oxygen for the enrichment of the air blast was the subject of fairly extensive trials in other countries before the war, but had not reached the stage at which definite proposals could be made for large-tonnage application. Here again the object is to secure quicker operation in the hearth, combined with lower gas velocities in the stack.

It has been established that with oxygen-enriched blast the temperature attained locally in the combustion area is raised to a marked degree. This higher temperature cannot be maintained in the presence of unmelted stock, and as a result of the greater heat differential between the products of combustion and the stock there is a more rapid transfer of heat and an increase in the rate of melting, giving a tendency towards increase of production. This tendency is, however, limited by factors which operate in the opposite direction.

It will be accepted that the lower gas volumes arising from the elimination of inert nitrogen will give lower gas velocities, increase the time available for heat transfer and ore reduction in the stack, and reduce the tendency towards channelling and flue-dust losses.

On the other hand, the greater absorption of heat in the bosh zone, combined with the decreased volume of gases formed, inevitably leads to a decrease in the quantity of heat passing up the stack. This effect increases as the percentage of oxygen rises until, with about 25% of oxygen in the blast, the quantity of heat available for preheating in the stack is inadequate and the descending stock reaches the bosh unheated and unreduced. This means that solid coke must be consumed in the hearth for the heating and reduction of the ore. The point at which this balance is reached has not been clearly determined, and much further work—especially on full-size modern units—is urgently needed.

The economics of the process will be determined by the cost of oxygen. The price of oxygen made by the normal process for liquid oxygen is clearly prohibitive, and here again a great deal of work must be carried out to provide commercial oxygen at a reasonable price before the process can be applied on a large scale.

SUMMARY

The increasing demand for pig iron and the proportion of small obsolete furnaces in the country emphasizes the necessity for the building of modern capacity. It is agreed that this new and replacement tonnage should be provided in modern units of the largest economic size and forming part of integrated works. The first essential factors for regular working and efficient operation are the thorough preparation of the ores and, especially on British-ore burdens, to grade, screen, and classify the ores. All fines below, say, ½-in. mesh should be removed and sintered.

Coke should as far as possible be made at coke ovens under the control of the pig-iron maker and should be made where necessary from blended coal mixture. The coke must then be crushed, screened, and classified, all small coke being removed and used for other purposes.

Where necessary, the ores should be put through a bedding plant to secure greater uniformity of composition.

The charging of the furnace must be in layers of material with a small range of sizes.

Three possible methods of increasing production and improving efficiency have been suggested, namely, (1) compensated charging, (2) high-top-pressure operation, and (3) oxygen-enrichment of the blast, but all three proposals still require much further investigation before any can be recommended for general adoption.

More detailed knowledge of the physical properties and reducibility of ores, and improved methods of sintering, are urgently required to give a sound foundation to the ore-preparation processes.

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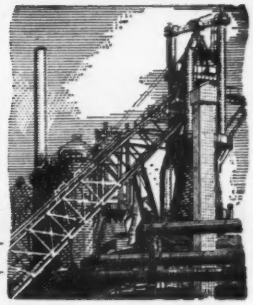

The Maintenance of Blast-Furnace and Ancillary Plant

By Arthur Bridge

Introduction

If one said that the maintenance of modern blast-furnace and ancillary plant incorporated every known branch of engineering such a statement would not be far from the truth. It would, however, require many volumes to cover the subject in its entirety, and it will be necessary to confine this section of the Conference to a review of the general principles and to repairs of special interest connected with the day-to-day maintenance of a large and modern plant, with a brief account of the measures adopted.

Before proceeding, it should be stressed that the very essence of ironmaking is continuity of operation, and therefore all plant and machinery necessary to the process must have a very high availability factor if efficient production is to be maintained. This, together with the fact that large quantities of molten materials have to be handled, makes a blast-furnace plant so different from the normal type of factory, which in all probability operates on a 40-hr. week basis as against the 168-hr. week of the ironmaking industry. From this aspect alone it will be realized that the maintenance of continuously operating plant is very different from, and more difficult than, maintenance as generally accepted in other spheres.

The necessity for maintenance in any plant can in general be classified as being due to the following factors:

(*a*) Fair wear and tear.
(*b*) Faulty operation. (Due to the human element, lack of trained personnel, etc.)
(*c*) Premature failure. (Due to faulty design, materials, or workmanship.)
(*d*) Accidental damage. (Due to extraneous circumstances, fire, storm, tempest, etc.)

It will be seen from the above that only group (*a*) lends itself to planned maintenance, and while items in group (*b*) can to some extent be anticipated, those in groups (*c*) and (*d*) are always unexpected and therefore cannot be prepared for other than by the normal provision of storm-water pumps and fire-fighting equipment, etc.

On analysis, maintenance work can therefore be grouped as follows:

(1) Routine (inspections, servicing, and minor repairs).
(2) Periodic (major overhauls).
(3) Preparation of spares.
(4) Dealing with emergencies (breakdowns or accidental damage).

In a sound organization groups (1), (2), and (3) should not present any difficulties, and in this respect valuable information can always be gleaned from routine perusal of operational log sheets, inspection reports, charts, and recorders, and it cannot be too strongly emphasized that an intelligent study of the above will do more to prevent unexpected failures than anything as yet devised.

The elimination of unexpected shut-downs should be the target for everyone connected with the maintenance of any plant, and when it is realized that on a modern blast-furnace plant the input of raw materials to the ore crushers alone may be in the region of 800 tons an hour, it will be appreciated how embarrassing an unexpected failure can be to the operating staff, to say nothing of the possibly far-reaching effects of the contingent repercussions.

Another feature relative to an emergency shut-down is the vital necessity for the maintenance staff to estimate as quickly as possible the length of time required to effect repairs. This information should be as reliable as possible in order that the operating staff can plan accordingly, as in the event of a blast-furnace being involved in the stoppage alternative fuels may have to be resorted to on other parts of the works, especially if the plant is an integrated one, and in cases of this kind first priority must be given

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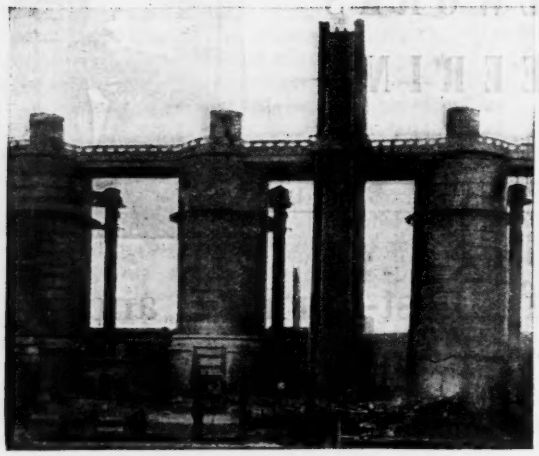

Fig. 1—Frodingham Ironworks, 1870

to the immediate task in hand at the expense of all other work.

The blast-furnace of today is rapidly approaching the stage when "ironmaking machine" would be a more appropriate description, and Figs. 1 and 2 show to some extent the development attained between the years 1870 to 1940, *i.e.*, during a normal span of human life, or "three-score years and ten." From these illustrations it will be quite obvious that with the mechanized development and contingent increase in size of the blast-furnace and its ancillary plant, the necessity for maintaining the equipment in a good state of repair is a matter of vital and increasing importance, as the larger the furnace the greater the production (and gas) loss each time the wind is taken off.

FURNACE MAINTENANCE

Hearth Repair

The occasion may arise during the campaign of any furnace when it is considered advisable to "blow-out" for a hearth rebuild only, *i.e.*, the complete renewal of the hearth brickwork from tuyere level downwards without disturbing anything above this level.

Such was the case at Appleby-Frodingham following a series of serious hearth breakouts on Nos. 9 and 10 furnaces, both of which have 22 ft. 0-in. dia. hearths, and therefore the problem to be solved was how to support the tuyere belt and all above, as high as the lintel, in such a manner that the hearth could be demolished and the salamander removed (by blasting) without damage to the rest of the furnace.

Careful investigation into the weight of structure to be supported—280 tons—was made, and the measure of success attained by the procedure adopted can be judged from the fact that the time taken for the task on the first attempt (No. 10 furnace) was 49 days, while a repeat performance on No. 9 furnace was accomplished in 29 days. The temporary supporting structure used for the job is shown in Fig. 3, in position, and a brief description of the procedure adopted is as follows.

The furnace was blown-out in the normal manner and the burden removed to a level about three feet below the tuyere centres. The 14 hearth coolers were replaced by 14 "dummies" in the form of tapered cylindrical sleeves 1 in. thick, through each of which was threaded a compound girder. It will be seen that the inner ends of these radial girders terminated at the centre of the furnace, while the outer ends protruded through the tuyere belt and were suitably supported on temporary stanchions adjacent to the outside of the hearth jacket. The inner ends were connected to crown plates attached to the key girder, which passed through two diametrically opposite dummy sleeves. To obtain the necessary strength to span the hearth and carry the loads in question, each girder was transformed into a lattice girder after positioning in the furnace, and the complete assembly was deck plated at top-flange level for the dual purpose of (*a*) protection of personnel from any loose material that may have fallen from the stack, and (*b*) protection of the bosh and stack lining from flying debris during the blasting of the salamander.

Where the top flanges of the radial girders passed through the dummy sleeves the space between the flange and the underside of the sleeve was packed with a cast-iron tapered saddle, thus ensuring that the girders took the weight. In addition to the 280 tons total weight supported by the 14 radial girders, each was designed to carry an additional live load of 5 tons on the bottom flange, to cover for any lifting tackle slung from it during the work in hand. A revolving post crane was also erected in the hearth, to facilitate the removal of the 21 stave coolers, each of which weighed about 5 tons and all of which had to be completely removed from the furnace and later replaced in a modified position. During the hearth repair to No. 9 furnace the time taken to erect the whole of the above structure was 26 hr., and the time taken to dismantle it on completion of the repair was 7 hr. A view of the interior of the hearth during

Fig. 2—South Ironworks, 1940

the process of rebuilding is given in Fig. 4 and shows the undisturbed brickwork below the hearth-cooler ports, through which one of the radial girders previously mentioned can be seen passing.

All the gear used in connection with the repairs described was made, erected, and marked for re-assembly in advance of requirement, in order that once the furnace had been taken out of commission there would be no annoying delay due to snags arising during the assembly of this fairly complicated structure within the furnace.

Casing Repair

To refer to the repair of a furnace casing in a paper of this kind would seem commonplace, but the unusual occurrence which necessitated the repair in question at the works with which the author is connected may be of some assistance to those who at some future date may experience a similar failure.

In September, 1940, the rivets in the circumferential seam joining the second and third tier of casing plates from the furnace top on No. 6 furnace failed completely, in shear, for the whole of the circumference of the stack and moved upwards for a distance of $1\frac{1}{4}$ in., or in other words half the lap. As the furnace was in blast and the national situation such that every ton of iron was of vital importance to the war effort, a provisional repair that would cause the least loss of production was the problem that confronted the maintenance department.

On the assumption that the pent-up stresses had

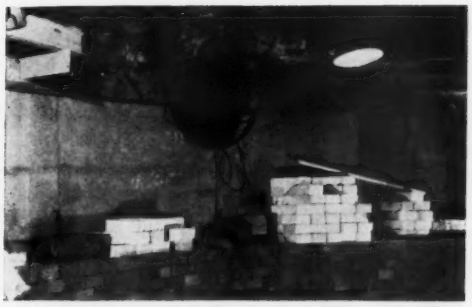

Fig. 4—Interior of hearth during repair

now relieved themselves, no action was taken on the evening of the occurrence other than to centre-pop each side of the defective joint at four points around the stack and appoint a watchman to trammel these marks every hour (blackout restrictions prevented welding commencing forthwith). The next move was to weld circumferentially the edge of the upper plate-lap to the lower plate, and this was accomplished during the following day. Then a circumferential packer flat was welded to the lower plate, just below the lap of the upper plate, and this in turn overlapped with a new circumferential cover strap in which clearance holes had been drilled to take the existing rivet heads (still fast in the parted top joint). Finally, vertical pad plates were welded on to the existing casing plates at 21-in. pitch, above and below the defective seam, and these formed the anchorage for welding the $48 \times 7 \times 1\frac{3}{4}$-in. thick bridge ribs, designed with a view to clamping the whole structure together again. The completed repair is shown in Fig. 5, and the furnace is still in service in this condition, the repair being such that when the furnace was off for relining in 1943 an examination revealed that no further attention was necessary.

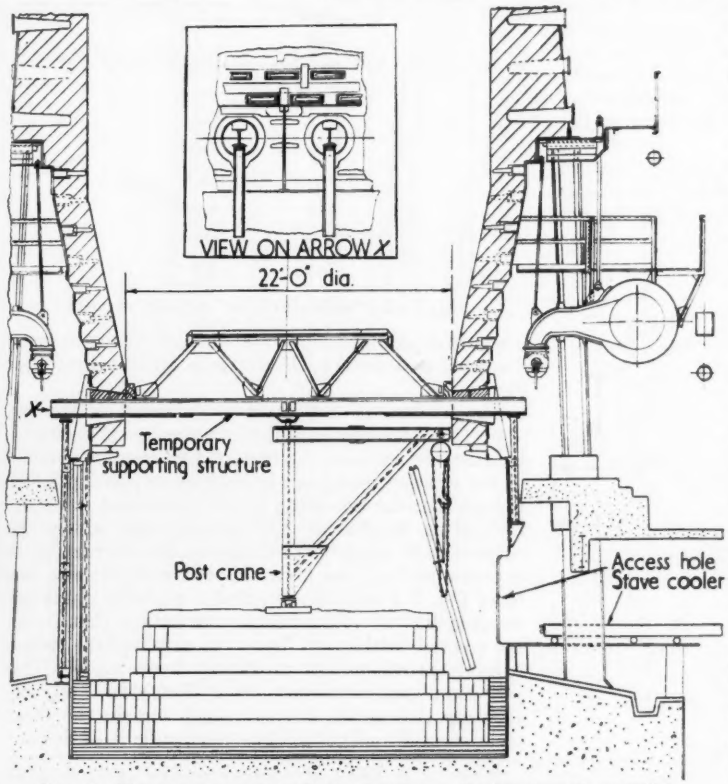

Fig. 3—Temporary supporting structure during hearth rebuild

It should be mentioned that the whole of this repair was carried out without wind being taken off the furnace, and therefore without delay to production, a satisfactory solution to a very difficult problem.

Top Repair

Another repair which may be of general interest was that in connection with the displacement of a mechanically charged furnace top and superstructure. The furnace concerned was No. 5 at Appleby-Frodingham, a bucket-charged (Pohlig type) furnace where the whole of the charging hopper and its supporting steelwork parted company with the furnace casing and was forced upwards to the

Fig. 5—Furnace-casing repair

amount of 6 in. on the west side and 9 in. on the east side. This, together with the contingent disturbance to the bell-operating gear and hoist-bridge supporting stools, gave rise to serious operating difficulties, *e.g.*, the charging-bucket seating was out of level, distribution was unequal, the bell did not seal, etc. Again conditions were such that production was vital to the war effort, and to avoid blowing-out the furnace the following procedure was adopted.

The furnace was kept in blast while eight substantial brackets were welded to the outside of the casing plates, the cap plates of which were located 12 in. above the existing top-deck level and from the top of which a steel grillage was built around the charging hopper, designed in such a manner that eventually the charging hopper, hoist feet, and bell-operating rig could be transferred from the defective to the new structure.

This transference of weight was carried out in stages each Sunday over a period of five week-ends with an average wind-off time of about 10 hr. per stage, and in addition to transferring the weight—106 tons in all—the whole had to be plumbed and levelled. The completed repair is shown in Fig. 6. Some twelve months later, at a more convenient date, the furnace was damped down for about ten days while the whole of the defective steelwork was removed from beneath the new structure and the crown brickwork entirely rebuilt.

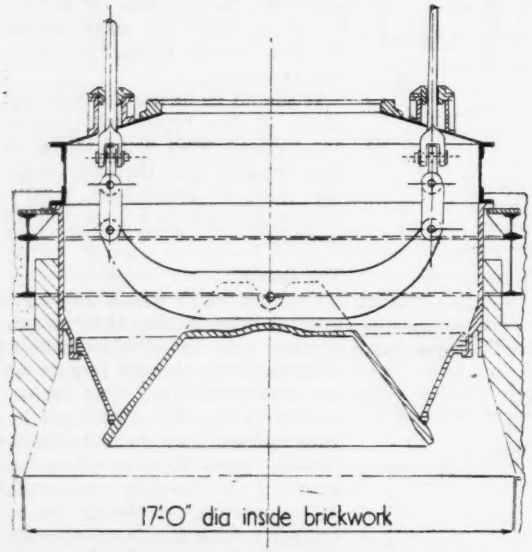

Fig. 6—Pohlig-type top structure after repair

The cause of the trouble was discovered some years later when the furnace was blown-out for relining, and was due to carbon deposition on the throat armouring.*

Bleeder Repairs

Repairs to bleeders are another maintenance problem, as very few furnace tops have provision for the changing of a defective bleeder assembly, and on integrated plants, where blast-furnace gas is in great demand, a defective bleeder is a prolific source of fuel waste.

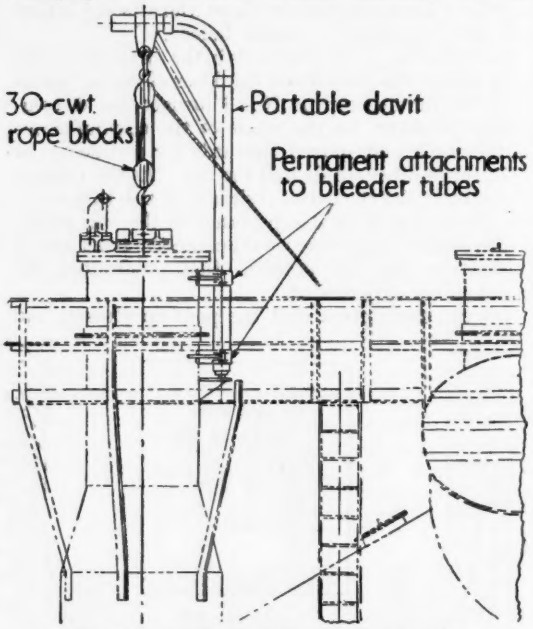

Fig. 7—Portable davit for bleeder repairs

The wisdom of a permanent cat-head or runway above the bleeders on a modern furnace is doubtful, because the corrosive action of the combined effect of the weather and gases in such an exposed position is such that the reliability of the permanent structure for lifting weights at this height must always be suspect. At Appleby-Frodingham an alternative to a permanent rig has been adopted with success, and from Fig. 7 it will be seen that a portable davit can be used for the job, with the advantage that it can be erected within an hour on any uptake where suitable provision has previously been made. This provision amounts only to a foot-step and two securing sleeves (in halves) which enable the davit to be secured and yet freely swung radially as desired.

* *See* G. D. Elliot, *The Iron and Steel Institute*, 1944, *Special Report No.* 30, p. 272.

Fig. 8—Time-and-job schedule for relining of No. 10 furnace, 1946

Table I

RELINING DATA, APRIL, 1945, TO DECEMBER, 1946

Furnace	Hearth Dia.	Work Done	Blown-Out	Blown-In	Time Taken, days
No. 5 ...	17 ft. 0 in.	Complete reline and minor modifications	Apr. 9, 1945 ...	June 11, 1945 ...	63
No. 1 ...	17 ft. 0 in.	Complete reline and major modifications	Aug. 12, 1945 ...	Oct. 7, 1945 ...	56
No. 10 ...	22 ft. 0 in.	Complete reline	Feb. 9, 1946 ...	Apr. 13, 1946 ...	62
No. 9 ...	22 ft. 0 in.	Complete reline	Nov. 2, 1946 ...	Dec. 16, 1946 ...	43½

When the defective bleeder has been replaced the davit can be dismantled and lowered down to ground level, where it can be stored and kept in a safe and sound condition ready for future service.

Relining

In considering relining, it is not the intention to deal with the reline of a furnace from A to Z, but rather to concentrate on the method adopted at Appleby-Frodingham in order to expedite the work involved. In these days of larger and fewer furnaces it is becoming more and more essential that when a furnace is taken out of service for a reline the work should be completed in the minimum of time, and with this in view special tools and tackle have been developed and used with success on the four furnaces relined at Appleby-Frodingham between April, 1945, and December, 1946. The progress attained to date is shown in Table I, and the times achieved were due to four main fundamentals, which are given hereunder in order of importance :

(*a*) A first-class team spirit by all concerned.

(*b*) A thoroughly discussed and fully agreed time-and-job schedule, issued before commencement of the work and with an objective to " beat it."

(*c*) The right tools and tackle for the job in hand.

(*d*) An incentive bonus payment, increasing in value with a reduction on the scheduled time.

The time-and-job schedule allocated for the relining of No. 10 furnace—which was blown-out on February 9th, 1946, and blown-in again on April 13th, 1946—is shown in Fig. 8.

A description of the method and equipment adopted for these jobs may be of general interest and is therefore briefly outlined in what follows.

The furnace is blown-out in a normal manner and the salamander tapped from the hearth bottom. A jubilee track is erected around the working platform, and the residue of the burden is raked out, loaded into skips drawn by a petrol locomotive, and dumped into tipping wagons in the normal service road ; this is followed by the felling of the old lining and its disposal in a similar manner, an access hole about 8×5 ft. being cut through the hearth jacket and stave coolers to facilitate demolition of the hearth.

A blasting cover is erected on a supporting structure threaded through the hearth-cooler holes, and a tight scaffold is also erected at lintel level to enable a start to be made on the brickwork of the stack while the removal of the old hearth is in progress.

A general arrangement of the entire relining rig is given in Fig. 9, which shows (*a*) the temporary steelwork around the hopper seating ring for supporting the four power-driven winches used in connection with the hanging telescopic stage separately shown in Fig. 10, (*b*) the service lift for material handling, guided on two ropes fixed at opposite corners and tensioned by means of hanging weights, (*c*) the adaptation of the furnace charging skips for the purpose of hoisting the bricks from the loading platform at ground level to the furnace top, and (*d*) the relative positions of the lintel scaffold and blasting cover. The whole of the above equipment is prefabricated, and fixing on the job is reduced to the barest minimum ; site drilling and riveting are not necessary, and only a very few bolted connections are required for assembly.

The large bell and hopper are clamped together ready for lifting, as a unit, from the furnace-top sealing ring, the total weight of the assembly being in the region of 46 tons, and special provision is incorporated in the design of the furnace-top structure for handling it.

FURNACE-AUXILIARIES MAINTENANCE

Stoves, Gas Mains, and Blast Mains

Generally speaking, maintenance in connection with the stoves, gas mains, and blast mains is negligible in comparison with that for other sections of the plant, and therefore it is not proposed to go into any detail on this subject other than to refer to a first-aid method of attacking a local hot spot due to a brick-lining defect in a hot-blast main. Several cases of this kind have been successfully repaired at Appleby-Frodingham in the following manner.

Where the brick lining has collapsed locally at the top of the ring and the outside of the main becomes red-hot in consequence, blast is taken off for abous three hours while the defective portion of the main it burnt out, the existing brickwork trimmed, a " false centre " made of $\frac{1}{16}$-in. thick plate inserted and suspended by $\frac{1}{4}$-in. dia. hangers tack-welded to the four corners of the burnt-out aperture, and the new brickwork built upon this false centre from outside the main, thus completing the ring. Afterwards, a new piece of steel plate is welded over the hole in the main. The completed repair is shown in Fig. 11.

It will, of course, be appreciated that in a repair of this nature it may be necessary, if the hole to be cut is a relatively large one, temporarily to prop the main on each side of the hole and between existing supports, otherwise the bridging effect of the main

may be destroyed and total collapse of the section of the main under repair may occur.

Ore Crushers

Where roll crushers are installed, there is one item of maintenance worthy of note, namely the preservation of the crushing-roll knobs and slugger teeth by means of weld metal.

At the Appleby-Frodingham South Plant there are two Hadfield two-roll primary crushers, each with rolls 6 ft. in dia. by 5 ft. long, and although these crushers have been in commission for over eight years the original roll shells are still in service, and, together, these two machines have crushed well over 17,000,000 tons of stone. The practice, right from installation, has been to reface the crushing knobs and slugger teeth each Sunday, two welders working on each crusher (one on each roll), the rolls being inched round for access as required. In cases where the wear is found to be excessive, rebuilding of the whole knob by weld metal alone is not attempted, the aim being rather first to weld on a steel pap with ordinary electrodes and then finish off with suitable hard-facing electrodes. An illustration of a complete roll shell as welded *in situ* is provided in Fig. 12 and is intended to convey an idea of the results that can be obtained by this systematic attention to crusher-roll shells. A point worthy of note is the access provided, which enables the welding to be carried out in a fairly comfortable position and thus facilitates good workmanship.

Belt Conveyors

Generally speaking, it is probably true to say that if there is one section of the raw-materials-handling plant in connection with the preparation of furnace burdens that does not receive the attention it merits in the design stage, that section is surely the belt-conveying systems.

In many instances the belts are of insufficient capacity to deal with the unavoidable surges that must occur on any plant fed from wagon tipplers. This is perhaps more pronounced on a plant dealing with home ores, which at times are wet and sticky, and the provision of surge hoppers to take care of these peaks would only provide a further source of trouble, as they would clog under certain conditions and so stop the flow of materials entirely. Surges of the nature referred to simply mean spillage over a considerable distance from each loading and transfer point, and as spillage

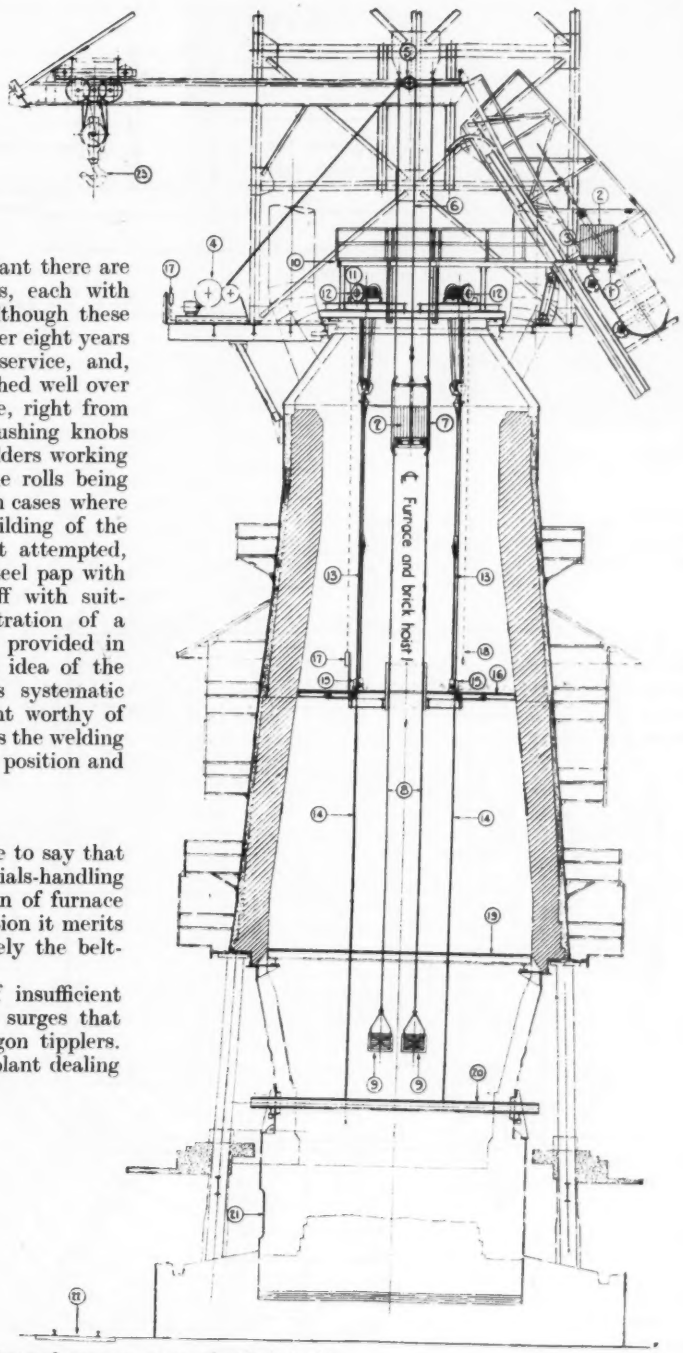

Fig. 9—General arrangement of relining rig

KEY

1 Temporary platform on furnace skip
2 Brick trolley
3 Hinged platform
4 Cage winch
5 Top pulley
6 Cage rope
7 Cage
8 Cage guide ropes
9 Tension weights for cage guide ropes
10 Superstructure
11 Supports for hoist blocks
12 Electric-hoist blocks
13 Rope slings
14 Safety ropes
15 Safety-rope clamps
16 Extending scaffold
17 Telephones
18 Push-button control for hoist blocks
19 Lintel scaffold
20 Blasting cover
21 Access hole in hearth jacket
22 Jubilee railway
23 Bell-lifting crane

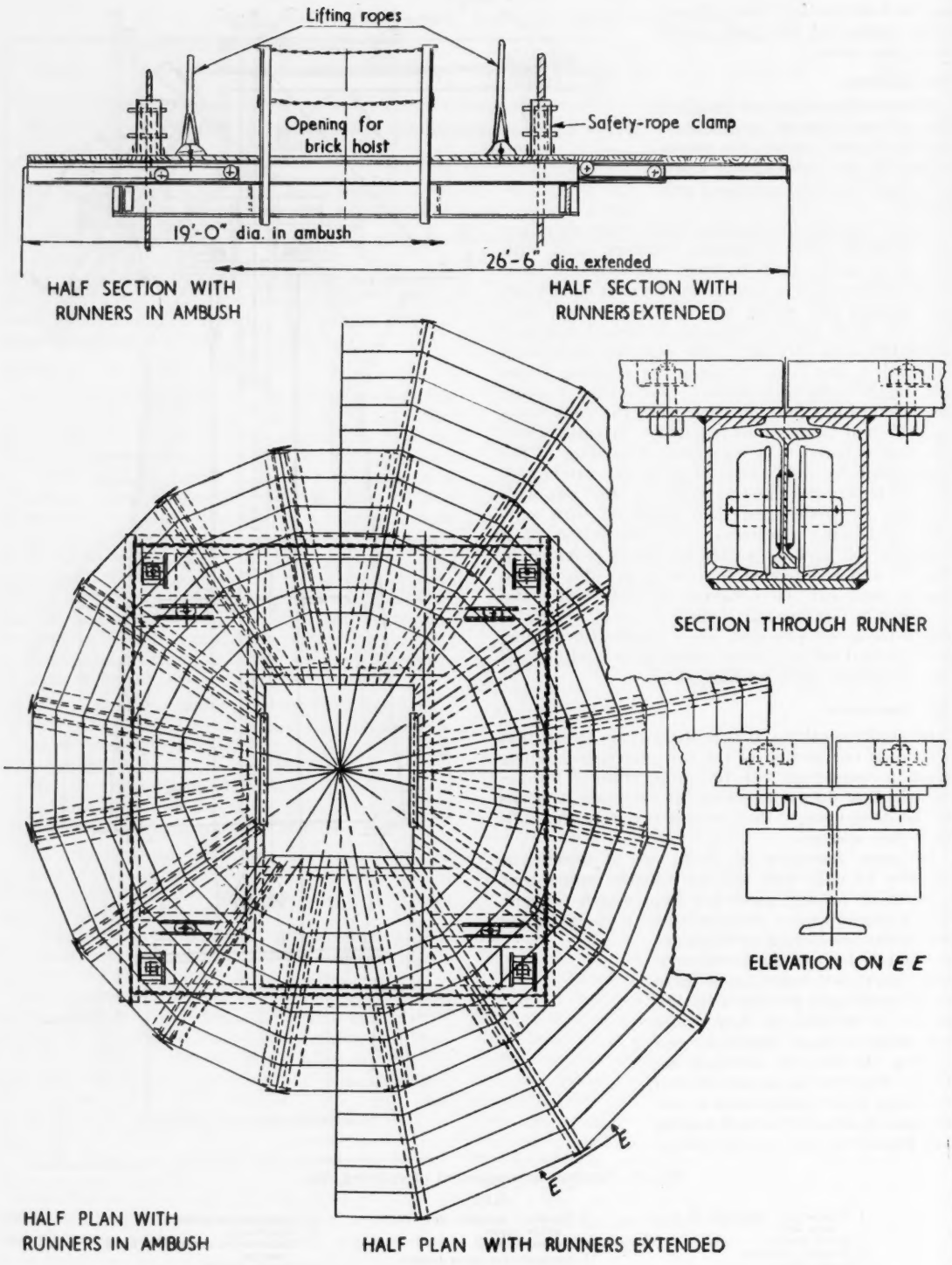

Fig. 10—Telescopic hanging stage

causes friction amongst the moving parts, wear and tear and failures are far more frequent than they need be. If such systems were designed well in excess of the anticipated nominal carrying capacity, the increase in installation cost would soon be repaid by a low maintenance cost, a cost which, by the way, is there for the duration of the life of the installation.

Quite apart from the above, there are still other features far from satisfactory in the design of belt conveyors as we know them today, and the maintenance problems to be solved before a really trouble-free system can be realized are many. For example, the enormous tonnage handled on a modern installation means that the loading points on a belt system are severely pounded, resulting in damage to the carrying surface of the belt and fractured idlers beneath the belt at these places, the latter in turn incurring further damage to the underside of the carrying belt. Maintenance troubles from this cause were so severe at Appleby-Frodingham that in certain locations it has been found necessary to install hammock belts, and by doing so the carrying life of certain conveyor belts has been increased from 1,000,000 to 2,000,000 tons.

Experiments are now proceeding with rubber-disc idlers for other loading parts subjected to heavy wear, and the results to date are very encouraging. Again, further thought should be given to a much simpler form of idler bracket for troughing idlers; the orthodox intricate cast-iron assembly could surely be replaced by a mild-steel fabrication, which, by its very nature, would be more suitable to withstand the shock loads to which such equipment is subjected.

Finally, that while the total elimination of dirt and spillage from belt conveyors handling ironstone, sinter, and coke, is perhaps not practicable, maintenance troubles would be eased if on all such conveyors the decking plates were designed on the inverted-**V** principle, so that dirt of any description would slide directly on to the floor at the sides of the conveyor, where it could be shovelled back on to the belt. At present the dirt has to be raked out on to the floor from around and between each set of idlers, where it lodges and in many cases prevents the idler rollers from revolving.

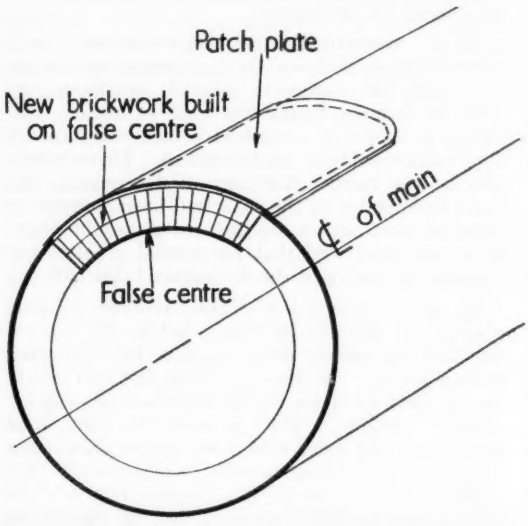

Fig.11—Hot-blast-main-lining repair

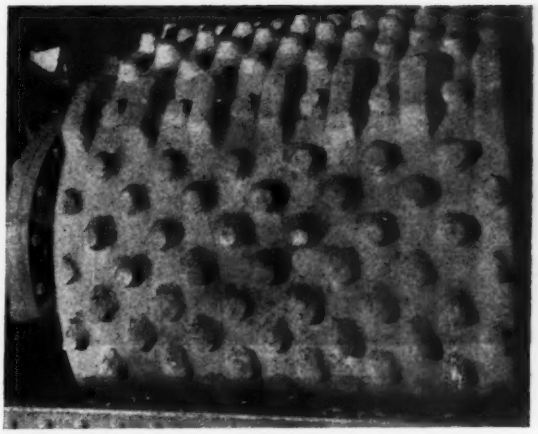

Fig. 12—Complete crusher roll undergoing rebuild of knobs

Sintering Plant

To do justice to the maintenance of sintering plants would require a complete paper. Under this heading the author therefore proposes to concentrate on only two items of maintenance, namely the main suction ducts and the main fans relative to continuous-belt machines.

To install unlined suction ducts is to ask for trouble, and on the plant with which the author is connected experience has proved this to be the case. The abrasive effect of particles of sinter on the unlined ducts was so severe that the maintenance of these ducts became a full-time job for a squad of boilersmiths and welders. Even so, it was impossible to keep pace with the erosion taking place, with the result that the quality of the sinter produced suffered through the leakage of air into the suction ducts, at the expense of air passing through the sintering beds.

When further repairs were not practicable it was decided to renew the entire suction ducts and to line the new ducts throughout, using hard-facing bricks. This was done, and subsequent inspections have shown that it is the answer to the problem. No further trouble has been experienced, and maintenance from this angle has been reduced to a negligible degree.

With regard to the main sintering fans, here again troubles are likely to be confined to erosion, and in the opinion of the author the fitting of internal wearing plates is not a satisfactory solution. So much trouble was experienced at Appleby-Frodingham with renewable wearing plates that in the end the original main fan casings (or what remained of them) were scrapped and new casings, made entirely of 1-in. thick plates and of welded construction, were installed without any wearing plates whatsoever, the idea being to carry out frequent internal inspections—say once per month—and at the first sign of erosion reclaim by weld deposits.

Fig. 13—Deposit removed from gas-washer-main bend shown alongside

By this method it is hoped to keep pace with the wear and tear.

The fan impellers have also been a source of heavy maintenance, but the sintering-fan manufacturers are now fully alive to this problem and are making good progress towards the elimination of the necessity for frequent renewals of the fan blades.

Chemical Descaling of Water Mains

The fouling of process-water mains and the like is an ever-present maintenance headache on any blast-furnace plant, and further research into the removal of scale and sludge deposits from service mains, heat exchangers, tuyeres, coolers, and boilers, is a matter to which merited attention may well be drawn.

There is no doubt whatever that if chemical treatment could be applied with confidence in a general rather than, as now, in an isolated way, the benefits to be derived therefrom in the saving of time and labour would amply repay the expenditure incurred in the investigation required.

With this in mind it is suggested that a full and comprehensive treatise should be prepared for the guidance of all iron (and steel) plant engineers, setting down the pros and cons, the whys and wherefores, and the do's and dont's, together with proved methods of procedure and recommendations as to the correct chemicals and inhibitors to use, and at what strength and temperature, for applications relative to the equipment desiring treatment.

Chemical treatment as practised today is largely limited to straightforward applications, as in any attempt to clean out a complex system the cure can quite easily turn out to be far worse than the complaint and may result in a complete shut-down of the plant, a state of affairs that no maintenance engineer would wish to stage, even in an attempt to be progressive.

At Appleby-Frodingham, chemical treatment is at present mainly confined to the cleaning of internal-combustion-engine water jackets, straightforward process-water mains, turbo-condensers, and waste-heat boilers of the fire-tube type; even so, care and caution have to be exercised if damage to plant is to be avoided. For example, it is a waste of effort to clean a condenser chemically only to find on completion that the tube-end grummets have all suffered from acid attack and require complete renewal before the condenser can be put back into service; furthermore, when using hot solutions caution is necessary because with increased temperatures the properties of the inhibitor may tend to be neutralized. A typical example of the incrustation to be found in a water main serving a gas washer is shown in Fig. 13, where the deposit was the product of ten years' operation and, as will be seen from the photograph, was removed intact from the bend shown alongside. To have attempted to remove this deposit by means of chemical treatment might or might not have been successful; however, the risk of lumps of deposit becoming displaced and causing a choke was considered to be too great to warrant the attempt, and therefore a temporary main was laid and the deposits removed manually.

The prevention of such deposits would of course be ideal if it could be realized in practice, but unfortunately that does not seem to be possible as yet. There is, however, the question of chlorination and the use of copper sulphate as a deterrent against certain other forms of fouling, but here again, unless incorporated in the system on installation, the remedy may be worse than the restriction to flow.

The above comments have been written with the object of bringing to light a very important aspect of maintenance, and to appeal for further research into the procedure and methods of application for a practice that could be greatly extended with beneficial results to all concerned, in which direction this country seems to lag behind the progress made in the United States.

From experimental work carried out at Appleby-Frodingham relative to the use of acid for descaling blast-furnace-gas-engine-cylinder water jackets, the following conclusions were drawn:

(1) When using commercial acids below 25% strength the concentration of the inhibitor need not exceed 1% by volume.

(2) A concentration of approximately 35% commercial acid gives the maximum attack on scale with the minimum loss of iron from any exposed surfaces during the time of attack. In actual practice, to maintain a concentration of 35% acid would be uneconomical. There would also be the further difficulty of determining the exact time at which the scale had been completely removed and attack on the metal would start. It is thus suggested that for normal practice the strength of acid used should remain below 20%.

(3) An increase in temperature reduces the time required to dissolve the scale, but in the case of cast iron the attack tends to make the remaining surface porous. In this connection, hot acid should not be used for descaling blast-furnace-gas-engine-cylinder jackets. The increase in the time necessary when using cold acid solution should not cause any great inconvenience, as even with a 10% solution the time required to remove 1 in. of scale should not greatly exceed 3 hr., if circulation is arranged for.

Blowers

For any type of blower to be used in connection with a blast-furnace, *reliability* as an essential, takes equal place with thermal efficiency, and this is all the more important on a plant where the practice is one blower, one furnace. The results of an unexpected failure in the supply of blast to a furnace are too well known to need reiteration in this paper; *anything* can happen, and therefore the maintenance of such equipment must leave nothing to chance. The amount of such maintenance is dependent on the type of blowing equipment installed; for instance, where gas engines are used the maintenance will be greater than would be the case with modern steam-driven turbo-blowers and their attendant boiler plant.

In the case of large gas engines of say 2000–5000 h.p., the large mass in motion gives rise to heavy wear and tear, and if the main bearings last fifteen years without renewal their life can be considered very satisfactory. The renewal of the main bearings in an engine of this size is indeed a major operation in itself, and great care has to be exercised if the anticipated life of the newly fitted bearings is to be realized. Crank web readings should be checked and recorded at least every six months.

It is also good practice to clean out the piston-rod stuffing boxes and the combustion chambers every eight weeks, and cylinder and exhaust-valve water jackets should be washed out periodically, but the frequency of this is dependent on the source and quality of the cooling water used. Acid treatment of water jackets is recommended in cases where deposits necessitate it, and an annual application of this treatment should be sufficient. With normal scale deposits, commercial hydrochloric acid diluted in the proportion of 1 gal. of acid to 6 gal. of water, with an inhibitor added in the required ratio to the mixture, can be used with confidence. The method of application can be varied to suit local conditions, but the solution should be circulated if the best results are to be obtained, after which the jackets in question should be thoroughly washed-out and inspected before closing-up again, ready for service. Before leaving the subject it might be useful to add that at least ten years' continuous service life should be obtained from the liners of the power cylinders, after which a rebore will probably be possible. With a suitable boring rig this rebore can be carried out *in situ*, and the trunk slides can also be trued-up with the same rig.

The maintenance of the modern turbo-blower should not amount to anything other than the periodic cleaning of the condenser and oil cooler, the former probably meaning a 24-hr. shut-down every twelve weeks. With careful attention to the lubrication system the life of the main bearings should be at least twenty years. An annual inspection of the steam-end and blower rotors is advisable as a precautionary measure, and, provided that a thorough overhaul is given during the period that the relining of a furnace is in progress, a turbo-blower should give a trouble-free run throughout a furnace campaign. With regard to the steam service to the turbo-blowers, modern water-tube boilers will, with good water and intelligent handling, give trouble-free service from one annual inspection to the next.

ADMINISTRATION

Remarks upon administration can be offered only for guidance, as the size and scope of the maintenance organization for any individual plant is entirely dependent on the size and location of the undertaking. There are, however, a few fundamental points worthy of review if the maintenance department is to operate efficiently, and the first and foremost of these is full co-operation with the operating staff. Too often instances are experienced where the operating staff have had the wind off a furnace for, say, tuyere changing, and within a matter of hours are approached by the engineering staff for wind off again in order that a minor repair can be executed. Such occasions should never arise, as in an efficient organization both jobs would proceed simultaneously. This is just one example of the necessity for full co-operation.

The team spirit of the department should be fostered to the utmost degree, not only from the point of harmonious working, but also from the point of saving costs. A contented and efficient maintenance department can work wonders with the minimum of manning (too many men can be worse than too few). A careful study of the job to be done, and the utilization of minimum personnel required to accomplish it, will be amply rewarded by the results obtained.

Incentives based on payment by results should always be considered in connection with all work undertaken by the maintenance department. In some instances there may be nothing to be gained by this, but in the majority of cases a saving in maintenance time, and costs, will accrue, to say nothing of the reduction in the length of a stoppage, with resulting savings in production loss.

Another aid to efficient maintenance is to have each item of plant distinctly marked with its respective plant number. This will save an enormous amount of work for the costing department by the avoidance of errors due to maintenance personnel booking their time to the wrong job, and will result in a more accurate record being kept relative to the respective maintenance costs for individual items of plant. It will also provide the yardstick by means of which spares can be ordered well in advance of requirements and so facilitate the planned maintenance which should be the inspiration and objective of the whole department.

With regard to routine maintenance, this should be scheduled from past experience and a standard procedure adopted wherever possible. For instance, a rope-changing sequence should be logged and a standard sheet for the job prepared from the data obtained. Such sheets could then be used whenever necessary, and would be invaluable in the case of the rope having to be changed by a new crew. This is only one instance, but from it will be seen the principle in mind.

Furthermore, short courses of training in methods of procedure relative both to personnel and job problems, organized for supervisors and held within

the works, will amply repay the time and expense incurred, and whilst it is at once admitted that mass-production methods are not generally applicable to maintenance work, great benefits can nevertheless be derived from the methodical approach to such work.

Another aid to efficient maintenance is the provision of a visible index on each important piece of mechanism, for the recording of such items as "glands last packed" or "new bearings fitted," etc. This can take the form of a card about 9 × 6 in., on which information is entered by the foreman at each repair. The card can be contained in a three-sided frame fitted to a plain wood-back panel and a perspex front, the whole assembly being attached to some suitable place on the machine. Such constantly visible records are invaluable, especially where prime movers and the like are concerned; the author has used them for over ten years and knows their worth.

The recording of inspection relative to pressure vessels and lifting appliances, etc., is well understood because it is a statutory obligation, but this system could be extended with advantage to other equipment, and on the plant with which the author is connected such extension is being carried out to an ever-increasing degree, with results that amply justify the appointment of the necessary personnel to organize and record such inspections.

Up-to-date instrumentation is a valuable asset on any plant, provided that full use is made of the information obtained therefrom. Charts from recorders, etc., should be the subject for intelligent routine examination, as they are the pointers to forthcoming trouble in addition to being continuous and reliable witnesses of plant operation. Only too often this valuable equipment is not used to the fullest extent, and it cannot be too strongly stressed that all personnel connected with the observation of these instruments should be fully informed as to the importance of drawing immediate attention to any abnormal variation from expected readings.

CONCLUSION

As stated at the outset, it is impossible to cover the subject of blast-furnace maintenance in detail in a paper of this nature, and many of the items dealt with, as well as many not even touched upon, could in themselves quite easily form the subject of a separate paper. The foregoing notes, while admittedly brief and sketchy, have been written with the object of helping others to overcome some difficulties with which they may not as yet have been faced. On the other hand they may have met and solved similar difficulties in some other, and perhaps better, manner and therefore be able to offer constructive criticism.

There must be many problems connected with the maintenance of blast-furnace and ancillary equipment with which engineers are battling on their own individual plants, and if only this knowledge could be tabled and tackled collectively in the same manner as the operating staffs are tackling their problems under the auspices of the British Iron and Steel Research Association, the results would be well worth while and a lot of valuable time and effort would be saved, thus helping to achieve that rate of progress on the engineering side of the industry which is so much desired.

One other aspect of maintenance, not as yet touched upon but the mention of which will not be out of place in a paper of this nature, is works' cleanliness and tidiness, or, in other words, *good housekeeping*. This is of paramount importance from a maintenance point of view, and there is no doubt whatever that a clean and tidy section of a plant is a trouble-free section. In the opinion of the author it is no exaggeration to say that 50% of all maintenance troubles can be traced to dirt—yes dirt—and in most instances unnecessary dirt. A dirty piece of plant is a deterrent to quality of craftsmanship during repairs on site, and greater attention should be paid to these locations with a view to improved cleanliness than has hitherto been the case.

Finally the epitome of plant maintenance is to maintain the plant in a good state of repair, with the minimum interference to production, the emphasis being on the last six words. This can be successfully achieved only by planned maintenance, the fundamental aim of which should be to give the minimum of service at the longest possible intervals, consistent with trouble-free operation.

Acknowledgments

The author wishes to express his thanks to the Directors of the Appleby-Frodingham Steel Co. for permission to publish this paper, and to those colleagues who have so willingly assisted with the preparation of the diagrams and photographs.

Two of the papers, presented at the Fifteenth Blast-Furnace Conference of the British Iron and Steel Research Association, on 26th–28th May, 1948, are published in this issue; the foregoing by Mr. A. Bridge, and the paper "Trends in Pig-Iron Manufacture" by Dr. T. P. Colclough and Mr. I. S. Scott-Maxwell, on page 186. It is hoped to publish a selection of other papers presented at the Conference, in future issues of the *Journal*.

N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Autumn General Meeting, 1948

The Autumn General Meeting of The Iron and Steel Institute will be held in London on 10th and 11th November, 1948. Full details will be published in a later issue of the *Journal.*

The Hatfield Memorial Lectures

Under a Deed dated 22nd August, 1944, the University of Sheffield agreed to be the Trustees of the fund which had been subscribed "for the purpose of establishing a lecture on the subject of Metallurgy, or some other subject connected therewith, as a Memorial to the late Doctor William Herbert Hatfield, Fellow of the Royal Society, and as a mark of appreciation of his distinguished work in connection with research into the qualities and uses of metals and allied branches of science." The lectures are to be known as the "Hatfield Memorial Lectures."

The lecturer is appointed by Sheffield University on the recommendation of a Lecture Committee, consisting of representatives of the University, the Royal Society, and The Iron and Steel Institute. At the discretion of the University the lectures may be published by The Iron and Steel Institute or by other publishers.

The First Hatfield Memorial Lecture (*Journal of The Iron and Steel Institute*, 1946, No. I, p. 369P) was given by Dr. George B. Waterhouse, on "*The Services to Metallurgy of the Late Dr. W. H. Hatfield, F.R.S.*" Dr. C. Sykes, F.R.S., presented the Second Lecture (*Journal of The Iron and Steel Institute*, 1947, vol. 156, July, p. 321), on "*Steels for Use at Elevated Temperatures.*" The Third Lecture (*see* p. 113 of this issue) was given recently by Dr. R. F. Mehl, on "*The Decomposition of Austenite by Nucleation and Growth Processes.*"

The late Dr. W. H. Hatfield, F.R.S.

(Born 1882; died 17th October, 1943)

WILLIAM HERBERT HATFIELD studied Metallurgy at University College, now the University, Sheffield, under Professor J. O. Arnold. In 1902 he won the Mappin Medal, received a grant from the Andrew Carnegie Research Fund to study carbon in cast iron, and presented, with Professor McWilliam, his first paper to The Iron and Steel Institute on the "*Elimination of Silicon in the Acid Open-Hearth Furnace.*" In 1913 he obtained the degree of D.Met. of Sheffield. He was the author of numerous technical papers on many branches of metallurgy, particularly rust-, acid-, and heat-resisting steels and of "*Cast Iron in the Light of Recent Researches*" (1912).

He obtained industrial experience with Sir Henry Bessemer and Co., Ltd., and Messrs. J. Crowley and Co., and in 1916 he was appointed Director of the Brown-Firth Research Laboratories, later also joining the Boards of Messrs. Thomas Firth and John Brown, Ltd., and their subsidiaries.

Dr. Hatfield served on many technical committees: he was Chairman of the Heterogeneity of Steel Ingots, Corrosion, and Alloy Steels Research Committees of The Iron and Steel Institute, the Programme and Finance Committee of the Iron and Steel Industrial Research Council, the Technical Advisory Committee on Special and Alloy Steels, etc., to the Iron and Steel Control, and he was a Member of a Metallurgical Mission to America in 1942.

Associated with many technical societies, he was a founder and the first President of the Sheffield Metallurgical Association, President of the Sheffield Society of Engineers and Metallurgists; Member of Council of Sheffield University, Fellow of the Chemical Society, the Institute of Physics, and the Institution of Chemical Engineers; and he was a Member of the Institution of Mechanical Engineers. In 1935 he was elected a Fellow of the Royal Society.

In 1928, Dr. Hatfield delivered the Campbell Memorial Lecture of the American Society for Metals, and in 1938 he gave the Tenth Gluckstein Memorial Lecture to the Royal Institute of Chemistry in London. He also received the award of the Compton Medal of the Institution of Automobile Engineers.

He joined The Iron and Steel Institute in 1903, and was elected a Member of Council in 1927, and became a Vice-President in 1934. He was awarded the Bessemer Gold Medal in 1933.

Seventy-Five Years Ago

In his paper "*On the Combustion of Powdered Fuel in Revolving Furnaces, and its Application to Heating and Puddling Purposes,*" presented at the Annual General Meeting of the Institute on 1st May, 1873, Mr. T. R. Crampton reported the results of experiments, during which more than 2000 tons of powdered fuel were consumed, carried out with the object of contributing towards the elucidation of the question of perfect combustion. To attain this an equal thickness of coal must be used, containing the same area of interstices in it, and a free access of air between the bars, and a regular pressure of air. The fuel must be in powdered form and fed regularly, together with air, by mechanical means so as to be independent of natural drafts.

The experiments were first carried out in a fixed combustion chamber, from which it was concluded that unless the undercharged and overcharged currents were brought together, good results could not be obtained.

The simplest method of grinding was found to be with a common flour mill, using Derbyshire gritstone. In large quantities coal could be ground for a rate of 9*d.* per ton.

The combustion obtained in these experiments was so perfect that cold scrap was welded with 5 to 6 cwt. of coal per ton of iron, with cold air, and without utilizing the heat in the chimney. Steel was melted in 1¾ hr., and 60 lb. of pure wrought scrap were melted in 3½ hr., without admixture of any kind. This demonstrates the perfection of the combustion, since the theoretical heat producible was only slightly greater than that of the melting point of wrought iron, and this result would have been almost impossible if variation of the quantities of air and coal had occurred.

A second experiment was made with a large marine boiler containing about 1500 ft. of surface. The fire bars were taken out, the furnaces were lined with fire brick, and coal and air were injected into them. The variation in the smoke-box temperature did not exceed 20° F. (380–400° F.) over a period of 24 hr., and 10–11 lb. of water could be evaporated with 1 lb. of fuel. It was impossible for smoke to be produced as the whole of the volatile matter was consumed in the first instance.

To investigate the subject further, experiments were made in a revolving combustion chamber, to which was attached a puddling chamber, the whole revolving together immersed in water. Charges of 5–6 cwt. of iron were puddled, with a gain in yield of 5–10%. The quality of iron produced was described as "somewhat remarkable," and it was estimated that 1 ton of iron could be puddled with 10 cwt. of coal.

NEWS OF MEMBERS

▶ Mr. W. D. BIGGS has taken up an appointment with Murex Welding Processes, Ltd., Waltham Cross.

▶ Mr. G. H. JACKSON is resigning his position of chief metallurgist to C.A.V., Ltd., to establish a consulting practice.

▶ Mr. IAN MCLEOD has taken up a position with Premier Colloid Mills, Ltd., Brettenham House, Strand, London.

▶ Mr. W. D. MARSH, until recently of Murex Welding Processes, Ltd., has taken up an appointment as a research metallurgist with Messrs. Hadfields, Ltd.

▶ Mr. G. T. MOTOCK has recently been appointed Director of Research and Development of the Champion Rivet Company, Cleveland, Ohio.

▶ Mr. J. G. PEARCE has been awarded the E. J. Fox Gold Medal for 1948 of the Institute of British Foundrymen.

▶ Mr. ALAN W. POSTLETHWAITE, who has recently been awarded an Andrew Carnegie Travelling Scholarship, has now left this country for America where he is to study powder metallurgy under Professor J. Wulff at the Massachusetts Institute of Technology. Born in 1924, Mr. Postlethwaite was educated at Chatham House County School, Ramsgate, and at the University of Sheffield, where he graduated with the degree of B.Met. in 1945. Since that date he has been employed as a research metallurgist at the Nelson Research Laboratories of the English Electric Co., Ltd., Stafford.

▶ Mr. F. W. ROWE is now Vice-Chairman of K. and L. Steelfounders and Engineers, Ltd.

▶ Mr. T. W. RUFFLE has resigned his position as metallurgist at Leyland Motors, Ltd., to take up a post as metallurgist with the Motor Industry Research Association.

▶ Mr. H. H. SHEPHERD has accepted an appointment with the Lister Blackstone Proprietary, Ltd., of Sydney, Australia.

▶ Mr. W. S. SPICER, of Messrs. Hadfields, Ltd., has retired after 47 years with the company.

▶ Mr. T. H. SUMMERSON has been made President of the Tees-side Chamber of Commerce.

▶ Dr. N. SWINDELLS has joined Messrs. McKechnie Brothers, Ltd., Birmingham, as chief metallurgist.

▶ Mr. F. WARDROBE has retired from the position of chief engineer of Messrs. William Jessop and Sons, Ltd., but remains a Director of the company and as a consultant on plant and engineering developments.

▶ Mr. J. J. WELTER has now left Luxembourg to take up an appointment at Buenos Aires as consulting engineer for the iron and steel plant that is to be constructed by the Argentine Government.

▶ Mr. P. WRIGHT, M.C., formerly assistant to the iron and steel works manager of the Workington branch of The United Steel Companies, Ltd., is now general manager at the Ministry of Supply factory, Monk Bridge, Leeds.

Memorandum

▶ The American Rolling Mill Company, Middletown, Ohio, announces that the name of the company has been changed to Armco Steel Corporation.

Obituary

The Council regret to record the deaths of:

Mr. CYRUS BRABY, of High Hurstwood, Uckfield, on 20th May, 1948.

Mr. ARCHIBALD JOHNSTON, a Director of Bethlehem Steel Corporation, on 2nd February, 1948, aged 83.

Sir WILLIAM J. TALBOT, of Talbot-Stead Tube Co., Ltd., Walsall, in December 1947.

CONTRIBUTORS TO THE JOURNAL

P. T. Hobson—Electronic engineer in charge of the Research Department of Messrs. Boosey and Hawkes, Ltd., and their associated company, Wirek (Electronics), Ltd. Mr. Hobson was born in 1911 and educated at Kent College, Canterbury. His previous activities included television research with the Baird Television Development Company, and the development of electronic applications to musical instruments, particularly to pipe organs. Mr. Hobson joined Boosey and Hawkes, Ltd., in 1939.

W. P. Osmond, B.A., B.Sc.—General scientist to the Research Department of Messrs. Boosey and Hawkes, Ltd., and their associated company, Wirek (Electronics), Ltd. Mr. Osmond was born in 1895 and educated at Bishop Wordsworth's School, Salisbury, and at Oxford University where, after serving in the 1914–18 war, he was awarded the degree of B.A. in 1919. In 1926 he obtained an external degree of B.Sc. of London University. From 1920 until 1939 he took up teaching and lecturing and then received a commission in the meteorological branch of the R.A.F.V.R. On his release from the Forces in 1945 Mr. Osmond joined the staff of Boosey

P. T. Hobson

W. P. Osmond

I. S. Scott-Maxwell

E. S. Chatt

and Hawkes, Ltd., and has since been engaged in the study of ferromagnetism in relation to alloys, and the quality of magnetic sound recording.

E. S. Chatt—Electronic engineer in the Research Department of Messrs. Boosey and Hawkes, Ltd., and its associated company, Wirek (Electronics), Ltd. Mr. Chatt joined the engineering staff of Boosey and Hawkes, Ltd., in 1942 and transferred in 1945 to their Research Department, where he is engaged on work in connection with magnetic sound recording.

I. S. Scott-Maxwell, Dipl. R.T.C., A.M.I.E.E., A.M.I. Mech.E. — Technical officer, British Iron and Steel Federation. Mr. Scott-Maxwell was born in Glasgow and educated at Oundle School, Northamptonshire, and at the Royal Technical College, Glasgow, where he obtained a diploma in electrical engineering in 1932. His practical experience was gained with Messrs. Alex. Stephen and Sons, Ltd., Glasgow, and with Messrs. A. Reyrolle, electrical engineers, Hebburn-on-Tyne. After being awarded an 1851 Exhibition industrial scholarship, he was employed for two years with the Central Electricity Board as assistant technical engineer for the Scottish Area. He then joined the staff of Messrs. Colvilles, Ltd., as assistant to the chief electrical engineer, and later became works engineer at Clyde Ironworks; in 1942 he was made works manager. Mr. Scott-Maxwell left Colvilles in 1946 to join the staff of the British Iron and Steel Federation, where he is particularly concerned with new developments under the industry's programme of expansion and reconstruction.

T. P. Colclough, C.B.E., D.Sc., and A. Bridge.—Owing to limitations of space, biographical notes of these authors will appear in next month's issue of the *Journal*.

IRON AND STEEL ENGINEERS GROUP

Engineering Committee

The Iron and Steel Engineers Group now has a membership of approximately 1350. On the recommendation of the Engineering Committee, it was agreed that changes in the membership of the Committee should be made each year, and the following members will serve until the Annual General Meeting in 1949:

Chairman

Mr. W. F. CARTWRIGHT	Steel Company of Wales, Ltd.

Members of Committee

Major W. R. BROWN, D.S.O.	Ashmore, Benson, Pease and Co., Ltd.
Mr. J. BUCHANAN	Priest Furnaces, Ltd.
Mr. H. S. CARNEGIE	English Electric Co., Ltd.
Mr. M. FIENNES	Davy and United Engineering Co., Ltd.
Mr. F. B. GEORGE	Consett Iron Co., Ltd.
Mr. D. C. HENDRY	Stewarts and Lloyds, Ltd.
Mr. J. F. R. JONES	John Summers and Sons, Ltd.
Mr. H. MARDON	British Iron and Steel Research Association
Mr. G. A. PHIPPS	Guest Keen and Nettlefolds, Ltd.
Mr. L. ROTHERA	Colvilles, Ltd.
Mr. F. SANITER	The United Steel Companies, Ltd.
Mr. Ben THORNTON	Wellman Smith Owen Engineering Corporation, Ltd.

Ex-Officio

Sir Andrew McCANCE, F.R.S.	President, The Iron and Steel Institute
The Hon. R. G. LYTTELTON	Honorary Treasurer, The Iron and Steel Institute

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Conference on Non-Destructive Testing of Castings

In collaboration with the Institute of Physics, a conference will take place on 8th and 9th September, 1948, at Ashorne Hill, near Leamington, to discuss non-destructive testing of castings. The discussions will be divided into three sessions:

Session 1—Papers on X-ray and gamma-ray methods, and X-ray equipment, radio-active materials and radiography abroad.

Session 2—Magnetic and ultrasonic methods.

Session 3—Recent work carried out by the Non-Destructive Testing Sub-Committee on the comparison of X-ray, gamma-ray, and ultrasonic methods, and a paper on acceptance standards.

It is intended that the papers shall deal essentially with the practical aspects of non-destructive testing and should be of interest to executives who may not be conversant with the methods, but who are considering their use.

30th Steelmaking Conference on Instrumentation of Open-Hearth Furnaces

The 30th Steelmaking Conference on Instrumentation of Open-Hearth Furnaces was held at Ashorne Hill, near Leamington, on 28th April, 1948. The attendance of 160 included representatives of most of the larger instrument manufacturers, and the conference therefore gave an opportunity for discussion of problems of instrumentation from the points of view of both makers and users. Some of the instruments now available for the control of open-hearth furnaces were exhibited during the conference.

Staff

Mr. R. T. EDDISON has been appointed Head of the Operational Research Section in place of Mr. D. J. Bishop, who has returned to the Ordnance Board. Mr. Eddison is now working under Dr. F. Yates, F.R.S., at the Rothamsted Experimental Station, and will take up his appointment on 1st July, 1948.

AFFILIATED LOCAL SOCIETIES

Manchester Metallurgical Society—Affiliation

The Council have pleasure in announcing that the Manchester Metallurgical Society has accepted an invitation to become affiliated to the Institute. This arrangement takes effect as from 1st June, 1948.

Mr. A. H. Goodger has been invited to be an Honorary

Member of Council of the Institute during his Presidency of the Manchester Metallurgical Society. Mr. J. A. Tod, of Imperial Chemical Industries, Ltd., Metals Division, Broughton Copper Works, Manchester, is Honorary Secretary of the Society.

NEWS OF SCIENCE AND INDUSTRY

Institute of Petroleum—London Branch

The inaugural meeting of the London Branch of the Institute of Petroleum was held in London recently. The field which the Branch intends to cover is wide and includes the economic, marketing, transport, utilization, and technological aspects of petroleum. Members and non-members of the Institute of Petroleum are eligible for membership of the branch, and there is no age limit. Forms of application for membership are available from Mr. N. E. F. Hitchcock, c/o Messrs. C. C. Wakefield and Co., Ltd., Research Department, Hayes, Middlesex.

Summer School in Electron Microscopy

A summer school in electron microscopy is to be held from 18th to 24th August, 1947, at the Cavendish Laboratory, Cambridge.

Royal Photographic Society: 93rd Annual Exhibition, 1948

The Ninety-Third Annual Exhibition of the Royal Photographic Society is to be held at 16, Princes Gate, London, S.W.7, during September and October of this year. It will be open in two parts, the first devoted to pictorial and colour photography, and the second to scientific, technical, nature, and record photography. The Exhibition is open to all users of photography and can assist them by giving a standard against which to judge their own work.

The scientific section of the Exhibition will include photomicrographs, radiographs, geological, metallurgical, and other branches of scientific and technical photography. Photographs produced in the course of scientific research will be particularly welcomed, especially if they illustrate the use of photography for obtaining information which could not be secured in any other way.

Two awards are made annually by the Society in the scientific section: the Hood Medal for meritorious performance in any branch of practical photography, and the Rodman Medal for outstanding work, preferably in photomicrography or radiography.

Further details and entry forms may be obtained from the Secretary of the Royal Photographic Society, 16, Princes Gate, London, S.W.7. The closing date for receiving entries is 24th July, 1948.

Mond Nickel Fellowships Committee

The Mond Nickel Fellowships Committee will shortly be meeting to consider applications for awards of Mond Nickel Fellowships for 1948. Those wishing to apply for an award who have not sent in completed forms of application should forward them without delay to the Secretary of the Mond Nickel Fellowships Committee, 4, Grosvenor Gardens, London, S.W.1.

CORRIGENDA

Liquid-Fuel Firing

Special Report No. 39 *: Reports of the Affiliated Local Societies*—The manuscript of the paper by F. A. Gray, entitled "*Liquid-Fuel Firing, with Special Reference to Open-Hearth Furnaces*," was received on 19th December, 1946, and not, as stated on p. 60 of the report, on 19th December, 1947.

Wire-Drawing Theory

The following corrections should be noted to the paper on "*Wire-Drawing Theory*," by G. D. S. MacLellan (*Journal of The Iron and Steel Institute*, 1948, vol. 158, Mar., p. 347): Page 349: in equations (2), (4), and (5), "F_s" should read "πF_s." Page 352, left-hand column, lines 16–19 should read "If the theory is a reliable guide, therefore, a reduction in the coefficient of friction from 0·10 to 0·05 means about a 40% increase in the ratio of the transverse 'splitting' force to the oxide force on the die."

DIARY

28th June–1st July—AMERICAN ELECTROPLATERS' SOCIETY—Convention—Atlantic City, U.S.A.

9th–16th July—INTERNATIONAL UNION OF PURE AND APPLIED PHYSICS—Conference on "*Physics of Metals*"—Amsterdam.

12th–16th July—ASSOCIATION FRANÇAISE POUR L'AVANCEMENT DES SCIENCES—Congress at Geneva.

12th–18th July—NETHERLANDS PHYSICAL SOCIETY—International Conference on the Physics of Metals, Amsterdam.

12th–21st July—Mechanical Handling Exhibition—National Hall, Olympia, London.

28th July–3rd Aug.—INTERNATIONAL UNION OF CRYSTALLOGRAPHY—Harvard University, U.S.A.

TRANSLATION SERVICE

(The previous announcement was made in the May, 1948, issue of the *Journal*, p. 82.)

TRANSLATIONS AVAILABLE

No. 344 (French). H. BERSOUX: "Life, Defects, and Scrapping of Rolls—General." (*Revue Universelle des Mines*, 1945, Series 9, vol. 1, Aug.–Sept., pp. 65–71).

No. 345 (Swedish). W. KARLSSON: "The Possibilities of Using Liquid Fuels in Iron and Steel Works." (*Värmlandska Bergsmannaföreningens Annaler*, 1946, pp. 47–94).

No. 346 (Swedish). E. BERNHULT: "The Calculation of Roll Pressure and Power in the Cold-Straightening of Bars and Tubes." (*Jernkontorets Annaler*, 1944, vol. 128, No. 4, pp. 137–160).

TRANSLATIONS IN COURSE OF PREPARATION

(French). M. QUILLATRE: "The Use of Wooden and Synthetic-Resin Bearings in Rolling Mills." (*Revue de Métallurgie, Mémoires*, 1941, vol. 38, Oct., pp. 253–271; Nov., pp. 285–298).

(German). G. NEUMANN: "How Can the Laws of Statics be Applied to the Design and Development of Furnace Roofs?" (*Archiv für das Eisenhüttenwesen*, 1942, vol. 15, Apr., pp. 437–445).

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the Series.

Increase of Charges

The Council announce that as from 1st July, 1948, the price of translations will be increased. The charge will be £1 for one copy of any translation in the Series, and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance.

Translations in the Series are not available on loan from the Joint Library.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

The Yorkshire Coalfield. L. Slater and A. M. Wandless. (Journal of the Institute of Fuel, 1948, vol. 21, Feb., pp. 131–143, 156). A comprehensive account is given of the seams of the Yorkshire coalfield with tables of data on analysis, reserves, production, and uses.—R. A. R.

Contribution to the Microscopical Study of the Phosphate Constituents of Lorraine Oolitic Iron Ores. Simonne Caillère and F. Kraut. (Comptes Rendus, 1948, vol. 226, Jan. 5, pp. 86–87).—J. C. R.

Mineral Deposits of the Sillimanite Group. J. Lougnon. (Annales des Mines, Mémoires, 1947, July, pp. 67–123). A detailed account of andalusite, kyanite, sillimanite, dumortierite, and mullite is presented, giving their appearance, composition, properties, the location of the deposits in the United States, France, and elsewhere, and an indication of their industrial applications. An extensive bibliography is appended.—J. C. R.

Tungsten Resources of Japan. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1718 : H.M. Stationery Office). Estimated reserves are small, of low grade, and probably insufficient to meet future requirements.

Iron Ore Resources of Japan. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1663 : H.M. Stationery Office). Domestic mines supplied only about 26% of the total iron ore requirements of the Japanese steel industry. An account of these resources is given.—R. A. R.

ORES—MINING AND TREATMENT

1947 Iron Ore Review. M. D. Harbaugh. (Blast Furnace and Steel Plant, 1948, vol. 36, Jan., pp. 49–53, 113). A review is presented of American iron-ore deliveries and consumptions during 1947, and ore reserves, mining, and benefication are considered. Shipments of iron ore loaded at Lake Superior ports totalled 77,898,037 gross tons, a peace-time record.—J. R.

Iron Ore and Beneficiation. G. T. Holt. (Mining Congress Journal, 1947, vol. 33, Feb., pp. 67, 70–73, 91 : [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 4). An account is given of iron ore production in the United States in 1946, subdivided by districts and distinguishing between open-cast and deep-mined ore. Processes for beneficiating the ores are outlined.

Latest Developments in Ore Dressing. S. R. Zimmerley. (Mining Congress Journal, 1947, vol. 33, Feb., pp. 39–42 : [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 14). Methods of concentrating lean ores, separation by flotation, and different processes for classifying and concentrating ores are described.

Sideritic Clays and Iron Ores of Périgord. V. Charrin. (Génie Civil, 1948, vol. 125, Mar. 15, pp. 109–111).

Beneficiation of Lean Oolitic Iron Ores of the Lorraine-Luxembourg Basin. N. Stoll. (Société Française de Métallurgie ; Revue de Métallurgie, 1947, vol. 44, July–Aug., pp. 221–227). Tests were carried out on the enrichment of Minette ore, by crushing, roasting, and magnetic separation. The ores were roasted in a reducing atmosphere, using blast-furnace gas and separated with a Davis electromagnet. It was sufficient to crush to 20 mm. initially, and roast at 450–650° C. for half the oxide to be converted to Fe_3O_4, which gave a sufficiently ferromagnetic product, but a final crushing of the roasted product to below 1 mm. was necessary for efficient magnetic separation. The ratio $(CaO - 1{\cdot}4\ SiO_2)/Fe$ for the concentrate varied between 0 and $-0{\cdot}5$; the degree of enrichment was considered satisfactory, except for ores mainly composed of γ-Fe_2O_3.—M. A. V.

German Magnetic Separator Applications, Particularly the Concentration of Minerals Feebly Magnetic. (British Intelligence Objectives Sub-Committee, 1948, Report No. 1696 : H.M. Stationery Office). German magnetic separators for treating mixed minerals such as wolframite and cassiterite are described.—R. A. R.

Iron Ore Beneficiation at Josephine Mine. C. A. Hames. (Transactions of the Canadian Institute of Mining and Metallurgy, 1947, vol. 50, pp. 637–656). A description is given of the crushing and flotation

plant at the Josephine Mine, Ontario, where a soft high grade of hematite is concentrated.—R. A. R.

The Metalliferous Sands of the Australian Coasts. Diana Mercer. (Chimie et Industrie, 1948, vol. 59, Mar., pp. 291–292). The eastern coast of Australia has deposits of monazite sands rich in thorium, zircon, rutile, and ilmenite. An outline is given of the methods employed for separating these minerals and of their industrial applications.—R. F. F.

Agglomeration of Khalilovsk Ores. F. I. Titov. (Stal, 1948, No. 1, pp. 14–18). [In Russian]. Results of full-scale experiments on the agglomeration of Khalilovsk ores are given.—S. K.

Reduction of Phosphorus Content in Iron Ore and Concentrate from Iron Mountain, Mo. H. Kenworthy. (United States Bureau of Mines, 1948, Feb., Report of Investigations No. 4199). Descriptions are given of tests to determine a method for reducing the phosphorus content of a finished mill concentrate of Iron Mountain (Missouri) ore to 0·18%—R. A. R.

Mesabi Range Changes Heavy Media Practice. E. C. Bitzer. (Mining Congress Journal, 1947, vol. 33, June. pp. 36–39: [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 14). Recent improvements have enable the heavy-media beneficiation practice on the Mesabi Range in force since 1938 to be extended. The beneficiation of medium-rich iron ores, spiral washing tests, thickeners, magnetic separators, recovery from middlings, and treatment of fines are dealt with.

Iron Ore Benefication Shows Healthy Growth. F. X. Tartaron. (Engineering and Mining Journal, 1948, vol. 149, Feb., pp. 110–113). A brief description is given of the first iron ore concentration plant to be erected on the Mesabi range for concentrating magnetic taconite iron ore.—R. A. R.

FUEL—PREPARATION, PROPERTIES, AND USES

Fundamentals of Combustion. H. C. McRae. (American Ceramic Society: Industrial Heating, 1948, vol. 15, Feb., pp. 238–244). The theory of combustion is explained in simple language, with special reference to the effects of too much and too little air and means of measuring the air/fuel ratio.—R. A. R.

Industrial Gas-Fired Furnaces. G. Hofmann. (Technik, 1948, vol. 3, Jan., pp. 31–39). A comprehensive account is given of the construction of gas-fired furnaces with special reference to burner design. Instrumentation and control are discussed with a view to recommending steps to ensure the most efficient use of the limited supply of gas at present available in Germany.—R. A. R.

Modern Design of Multiple Fuel Steam Units. A. R. Mumford. (Iron and Steel Engineer, 1948, vol. 25, Feb., pp. 88–98). Practical and theoretical considerations involved in the design of multiple-fuel steam-raising units are presented and discussed, and some of the factors influencing the availability of the units are outlined.—J. R.

Saving Electric Power in Industry. M. Hernberg. (Teknisk Tidskrift, 1948, vol. 78, Apr., 3, pp. 218–220). [In Swedish]. It is not generally known that electricity is rationed in Sweden, but the first rationing period is approaching its end and the author reviews the position in various industries consuming current and makes recommendations on methods of reducing consumption.—R. A. R.

Fuel Efficiency Tests for Metallurgical Works. R. Vagnair. (Flamme et Thermique, 1947, Apr.–May, pp. 20–29).

The Problem of the Reactivity of Solid Fuels. H. Guérin. (Chimie et Industrie, 1948, vol. 59, Apr., pp. 337–338). The work done by various investigators on the reactivity of solid fuels is reviewed.—R. F. F.

The Price Structure of Coal and Its Relationship to Preparation and Utilisation. E. S. Grumell. (Journal of the Institute of Fuel, 1948, vol. 21, Feb., pp. 109–130).

The Activation Energies of the Different Stages of the Oxidation of Carbon at High Temperature. R. Audubert. (Journal de Chimie Physique, 1947, vol. 44, Oct., pp. 230–232). Kinetic and photometric studies show that the oxidation of carbon above 1500° C. is a chain reaction. Thermodynamic equations are derived; these agree with practice.—R. F. F.

Technological Lay-out for Reconstructed and New Coal Preparation Plant. P. I. Preobrazhenski. (Stal, 1948, No. 2, pp. 107–116). [In Russian]. A detailed survey is made of methods for coal preparation applicable to the types of coal used in the U.S.S.R. After a consideration of preliminary classification, dust removal is dealt with, a flow-sheet being given. Wet desludging and coal concentration are discussed, the variations of the latter process for different kinds of coal being illustrated by flow-sheets, and the dehydration of the products is considered. Particular attention is given to the operation of sedimentation plant, the following points being discussed: (1) The recovery and treatment of coarse sediment and of the sediment from the wet desludging process; (2) the concentration of fine sediments; (3) the recovery of water from the dehydration plant; and (4) the concentration and treatment of secondary sediments. An equation is given for the length of a settling tank in terms of time for settling, rate of flow of water, and the width of the tank.—S. K.

The Cyclone as a Thickener of Coal Slurry. H. F. Yancey and M. R. Geer. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2351: Coal Technology, 1948, vol. 3, Feb.). An investigation of a thickener developed in Holland for coal slurry is described. It is of the cyclone type and it can thicken slurries to a content of 60–65% of solids. There is almost complete recovery of solids coarser than 200 mesh.—R. A. R.

Modernized Coke Producing Facilities Boost National Tube's Output by 800,000 Net Tons. (Steel, 1948, vol. 122, Mar. 22, pp. 92–100). **Modern Coal Handling System Important Unit in Lorain Expansion.** (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 44–46). **Annual Coke Production at Lorain Works Increased by 800,000 Net Tons.** (Blast Furnace and Steel Plant, 1948, vol. 36, Mar., pp. 325–331). A description is given of the three batteries of coke ovens recently constructed at the works of the National Tube Co., Lorain, Ohio. Each battery consists of 59 underjet-fired ovens, 39 ft. long, 10 ft. high, tapering in width from 21 in. to 17 in. The gas-collecting mains are designed to reduce the smoke during charging operations.—R. A. R.

Experimental Study of Heat Regenerators for Coke Ovens. H. Cassan. (Chaleur et Industrie, 1948, vol. 29, Mar., pp. 55–73). A mathematical account is presented of experimental studies with heat regenerators for coke ovens and means of improving their efficiency. The author discusses the results obtained and explains how they can be interpreted and utilized.—J. C. R.

Examination of a Pellet of Coke as a Measurement of the Agglutinating Power of Coals. G. Gaikorst. (Gas, The Hague, 1947, vol. 67, Aug. 1, pp. 167–168).

The Relation of Free-Swelling Indexes to Other Characteristics of Some Alabama Domestic Stoker Coals. R. Q. Shotts. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2314: Coal Technology, 1948, vol. 3, Feb.).

Removal by Suction of the Gases from the Chambers of Coke Ovens. B. I. Koostov and A. I. Voloshin. (Stal, 1948, No. 1, pp. 6–10). [In Russian]. Three series of experiments were performed in 1946 in order to find the method of removing the gases from coke ovens best suited to operating conditions in the U.S.S.R. The experiments were carried out on a battery of Becker ovens and involved, besides the usual operational observations, the continuous measurement of roof temperatures, the temperature of the charge and the pressure at the chamber-floor. In the first series of experiments, when only one gas off-take per chamber was used, higher roof temperatures and poorer yields of by-products were obtained, and the working conditions at the ovens were more difficult. Improvement was found both in the second and third series, when both gas off-takes were used, and in the third series, where lower oven pressures were also used, gas losses and coking times were diminished.

These experiments show that the use of two gas off-takes per oven should be adopted in the U.S.S.R.—S. K.

Coke-Oven Management. (Coke and Gas, 1948, vol. 10, Mar., pp. 96–97, 101). The importance of good management in the coking industry is discussed with special reference to the linkage between coking and gas industries envisaged in recent legislation.—R. A. R.

Pioneering the Use of Coke-Oven Gas. A. C. Middleton. (Coke and Gas, 1948, vol. 10, Feb., pp. 64–67). The author describes the gradual development of the supply of gas from Rotherham Main coke ovens during a period of just over 40 years.—R. A. R.

The "Critical Air Blast Test." F. G. Kreulen, van Selms, and D. J. W. Kreulen. (Chemisch Weekblad, 1948, vol. 44, Apr. 10, pp. 208–211). [In Dutch]. The critical air blast test of H. E. Blayden, W. Noble, and H. L. Riley (*see* Journ. I. and S.I., 1934, No. I, p. 445) for determining the combustible nature of coke is described, and results obtained with it on various cokes and coals are presented and compared.—R. A. R.

The Thermal Efficiency of Gas Producers, with a Discussion of the Relative Merits of Producer-Gas and Stoker Firing for Chemical and Other Plant. C. Dunningham. (Journal of the Institute of Fuel, 1948, vol. 21, Feb., pp. 144–155). *See* Journ. I. and S.I., 1948, vol. 158, Jan., p. 148.

A New Method of Power Generation from Blast-Furnace Gas. M. Ehlinger. (Energie, 1948, vol. 32, Feb., pp. 29–34). A new type of gas engine, with oscillatory blades in place of pistons, drives a compressor of similar design; this compresses blast-furnace gas for use in the gas engine, as well as air. The compressed air, mixed with the exhaust gas, drives a gas-turbine alternator. Similar gas-engine compressor units are suggested for production of blast.

For cleaning blast-furnace gas the "Dialithe" process is described. In this, gas cleaned in cyclones to 5·0 g./cu. m. passes horizontally through vertical columns of coarse sand, where the dust content is reduced to 0·020 g./cu. m. The sand columns are regenerated in sequence from time to time by screening; the flue dust is recovered and the sand returned for further service.—J. P. S.

The Use of Producer Gas or Fuel Oil in Metallurgy. G. Marin. (Energie, 1948, vol. 32, Apr., pp. 99–103). The use of producer gas for metallurgical purposes is compared with fuel oil. The conversion from producer gas to fuel-oil firing of reverberatory furnaces of the Wichwire Spencer Steel Division is described and the advantages gained discussed.—R. F. F.

TEMPERATURE MEASUREMENT AND CONTROL

The Measurement of Molten Iron and Steel Temperatures. R. G. Ackland. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy, Part 4, Physical Apparatus for Metallurgical Measurements, 1947, Sept.). A comprehensive account is given of the principles and present stages of development of the following pyrometers: (1) Total-radiation, optical, and photo-electric pyrometers; and (2) tungsten-graphite carbon/silicon-carbide, and platinum/platinum-rhodium thermocouples. The advantages and limitations of each are outlined.—R. A. R.

Maintenance Methods Symposium—Maintenance of Temperature Indicating and Recording Instruments. H. C. Morrow. (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 93–96). A description is given of the system of instrument maintenance at the hot strip mill and tinning plant of the Carnegie-Illinois Steel Corporation.—R. A. R.

High Temperatures. Their Production, Measurement and Use. R. S. Hutton and M. Pirani. (Research, 1948, vol. 1, Feb., pp. 204–207). The literature on recent advances in the production of very high temperatures (above about 1600° C.), their measurement and use is surveyed.—R. A. R.

REFRACTORY MATERIALS

British Resources of Ganister and Silica Rock. W. Davies. (Refractories Journal, 1947, vol. 23, Dec., pp. 418–429: Transactions of the British Ceramic Society, 1948, vol. 47, Feb., pp. 53–81). The history of silica brickmaking in Great Britain is first reviewed briefly, and selection of suitable raw materials is considered, attention being paid to texture, grain-size, and other physical characteristics. The terms "quartzite" and "ganister" are clarified, and the distinguishing features and geological development of various types of silica rock are explained at length and their distribution illustrated. It is concluded that, on account of progressive exhaustion of the resources of high-quality ganister, the silica brick industry may use quartzitic sandstones increasingly in the future, and that research may be able to show how quartzitic sandstones can be used without detriment to the finished product; it is also considered that the mining of ganister may again become an economic proposition.

An Improved Hydration-Expansion Apparatus. W. F. Ford and W. J. Rees. (Transactions of the British Ceramic Society, 1948, vol. 47, Feb., pp. 87–90). An apparatus for more accurate routine measurements of the hydration-expansion rates of normal dead-burned magnesites is described. Linear variations in the height of a moist American Foundrymen's Association test-piece, resting on a hot floor of constant temperature, in an atmosphere of constant humidity, are compared with the negligible expansion of fused silica.—R. A. R.

Initial Care of Refractories. R. Jones. (Iron and Coal Trades Review, 1947, vol. 155, Aug. 1, pp. 225–227). The importance of careful treatment in the warming up of silica brick roofs and ladle linings, particularly in the 200–275° C. range, is stressed and a description is given of a portable coke-fired unit called the "Prestatyn" heater. This carries a heat-discharge outlet the position and length of which can be altered to suit the lining which is to be dried and preheated.—R. A. R.

The Changes Occurring in Blast-Furnace Stove Refractories during Service. J. Mackenzie. (Transactions

of the British Ceramic Society, 1948, vol. 47, Mar., pp. 91–107). An examination of various brands of refractories has been made during two years' service in a hot-blast stove. The extent of vitrification and the relationship between vitrification and thermal shock resistance has been followed by measuring the variations in rigidty of the specimens during use. It has been found that initially most firebricks tend to vitrify and increase in rigidity, but that after a certain period this increased vitrification leads to poor thermal shock resistance and the formation of numerous cracks in the refractory and thus a considerably altered measured modulus of rigidity. The ideal material for a blast-furnace stove seems to be a hard-fired high-alumina brick which has a superior resistance to slag and vitrification, and is therefore less likely to change its rigidity in use and thus set up stresses in the refractory between the vitrified and unvitrified portions. The siliceous types of firebrick show a reasonably constant rigidity since any vitrification is compensated by the natural bloating of this material, but the "potty" nature resulting makes this brand on the whole inferior to the higher alumina qualities.

The Properties of Basic Fettling Material in Open-Hearth Furnaces. A. S. Berezhnoi. (Stal, 1948, No. 1, pp. 28–36). [In Russian]. An account is given of investigations into the main physical properties and the stoichiometric and phase composition of samples of fettling materials from a number of works, and the results are summarized in tables and diagrams. A mechanism is suggested for the fettling process and for the changes which ensue during the furnace campaign both for magnesite and magnesite-dolomite materials.

Equilibrium had not been reached in a number of samples and the phase compositions were calculated as for Portland cement clinker. The main phase appeared to be periclase, which made up 55–68% of the fettling layer before use; the total content of iron and manganese oxides, ferrites, and aluminates varied widely, but was most frequently about 15%; and the mean silicate content was about 20%. An important factor in the properties of the fettling layer is the amount of melt produced at working temperatures; and this amount was found most frequently to be about 25%, though it varied not only from sample to sample, but also from layer to layer of the same sample. The range of porosities found in the samples examined was 7·5–27·6%.

The refractoriness of magnesite fettling was found to be >1900° C., which is higher than that of magnesite-dolomite; but owing to the formation of easily fusible eutectics in the former and the presence of good periclase bonding in the latter, the temperatures of deformation under a load of 2 kg./sq. cm. were 1440° and 1630° C., respectively. Thus both types of fettling material must be in a softened state when covered by the molten metal. A number of micrographs of sections of samples of fettling are shown, and it is seen that, in accordance with theory, the periclase grains in most samples were cemented by orthosilicates of the series Ca_2SiO_4-Mg_2SiO_4 (or by Ca_3SiO_5 and Ca_2SiO_4 in the case of magnesite-dolomite fettling). The optical properties of the phases are discussed.

On the basis of these investigations the following suggestions are made: The periods during which the open-hearth furnace remains uncharged should be reduced to a minimum as the volume changes which result from the oxidation of the magnesia-Wüstite phase cause mechanical strains in the fettling layer; the addition of silica or alumina to basic fettling material should be avoided as melts are then formed which are difficult to remove; the use of synthetic magnesia-containing powders for fettling should be extended as this facilitates both fettling and repairs to the hearth.—S. K.

Furnaces—Refractories and Forging Costs. H. J. Shaner. (Steel Processing, 1948, vol. 34, Jan., pp. 41–43). The advantages of using insulating bricks for lining forging furnaces are outlined and the precautions to be taken to obtain the optimum results are indicated.—R. A. R.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

A New Blast-Furnace at Tollcross. (Engineer, 1948, vol. 185, Mar. 19, pp. 285–286). The new blast-furnace of Messrs. Colvilles Ltd., at Clyde Iron Works is described (*see* Journ. I. and S.I., 1948, vol. 158, Mar., p. 394).—R. A. R.

New French Blast Furnace. (Iron and Coal Trades Review, 1948, vol. 156, Mar. 19, p. 601). Brief particulars are given of a blast-furnace now under construction at the works of Forges and Aciéries du Nord et de l'Est, at Valenciennes. The hearth is 6·5 m. in dia. The volume is 900 cu. m., and it is designed to produce 700 metric tons/day.—R. A. R.

Hot Blast Stove Gas Burner Gives Soft Mellow Flame. S. P. Kinney. (Blast Furnace and Steel Plant, 1948, vol. 36, Feb., pp. 217–219). A description is given of an improved type of gas burner for blast-furnace stoves. The burner is designed for use with clean, semi-clean, or dirty gas and the combustion air is automatically regulated to the heating time.—J. R.

Blast Furnaces in the Ruhr and at Watenstedt. (Combined Intelligence Objectives Sub-Committee, 1948, File No. XXXIII-56: H.M. Stationery Office). Blast-furnace plant and practice in the Ruhr and at Watenstedt are reviewed with data on furnace profiles and dimensions. In general, carbon linings have greatly increased production, but the furnace must be correctly proportioned for the ore being smelted and such factors as distance of the tuyeres above the hearth bottom, and bosh angles are very important. Stove equipment is, on the whole, of much more modern design than the furnaces. Trials were made at Hamborn with compound tuyeres constructed by fitting a 2-in. dia. water-cooled pipe in the centre of the ordinary tuyere; this pipe was supplied with air at 35–37 lb./sq. in. The volume of high-pressure air through all the pipes was 15–20% of the total air delivered to the furnace. The effect was to increase the combustion zone to an area approaching that of the whole hearth and to increase the coke burnt from 800 to 1120 tons/day. The tests were stopped owing to failure of the water-cooling at the end of the 2-in. pipe.—R. A. R.

Smelting of Basic-Bessemer Pig Iron from Low Grade German Ores in the Blast-Furnace with Acid Slag Practice. W. Lennings. (Iron and Steel Institute, 1948, Translation Series, No. 341). This is an English translation of a paper which appeared in Stahl und Eisen, 1938, vol. 58, Jan. 13, pp. 23–34; Jan. 20, pp. 52–88. (*See* Journ. I. and S.I., 1938, No. I, p. 240A).—R. A. R.

Blast Furnace Experiments at Neuves-Maisons Using an Oxygen-Enriched Blast. M. Platon. (Centre de Documentation Sidérurgique, Circulaire d' Informations Techniques, 1948, vol. 5, Jan. 25, pp. 45–58). An account is presented of four classes of experiments carried out at Neuves-Maisons with a view to increasing production and reducing fuel consumption by using a blast as rich in oxygen as possible. First, a dry oxygen-enriched blast using one set of tuyeres was employed; secondly, two sets of tuyeres were used with blasts of different oxygen content; thirdly, two sets of tuyeres were

used and the blast in either the upper or lower set included steam ; fourthly, two set of tuyeres were used with blasts containing steam and fuel oil. The experiments were conducted with Maron ore (33% Fe) and the coke consumption was kept constant. The results obtained are tabulated and the reactions that take place within the furnace are discussed.—J. C. R.

The Oxygen Blast—A New Step in Metallurgical Developments. I. P. Bardin. (Bulletin de l'Académie des Sciences de l'U.R.S.S., Classe des Sciences Techniques, 1947, Oct., pp. 1363–1368). [In Russian]. A review is presented of development in the use of oxygen-enriched blast in the Soviet Union.

Utilization of Oxygen in Smelting Low-Grade Ores. W. M. Pollitzer. (Steel, 1948, vol. 122, Feb. 16, pp. 98–104). A description is given of the low-shaft blast-furnace using oxygen-enriched blast at Trostberg, Bavaria. The results obtained with it are discussed. *See* "Utilization of Oxygen in the German Iron and Steel Industry" (Journ. I. and S.I., 1948, vol. 158, Mar., p. 395).—R. A. R.

The Influence of Stockline Level on the Distribution of Material and Gas Streams in the Blast-Furnace. A. N. Redko. (Stal, 1948, No. 2, pp. 117–125). [In Russian]. A series of tests was carried out in 1946 at the Kuznetsk works to see to what extent adjustment of stockline level could be applied as an additional means of furnace control "from the top." The blast-furnace used was provided with apparatus for determining the distribution of materials on the big bell, for taking gas samples from the stack along a radius of the furnace, and for recording the distribution of the blast among the tuyeres ; the throat was of the Venturi type, the top of its cylindrical part being at a depth of 1·3 m. below the lowest level reached by the base of the big bell, while the stockline was normally at a depth of 0·6 m. below this level. The lime, agglomerate, and open-hearth slag of the burden were artificially moistened, thus reducing dust output and increasing the inclination to the horizontal of the layers of ore in the furnace, and an ore mixture was used which kept the iron content of the burden above 44·6%.

It was found that lowering the stockline level from 0·6 to 2·8 m. altered the distribution of materials in the stockline and of gas streams along a furnace radius, as well as the speed of descent of the burden at points along this radius. When the stockline was lowered to 2·3 m. its inclination to the horizontal decreased (that of the top of the layer of ore always being smaller than that of the layer of coke), as did the difference between the speeds of descent of the burden at the centre and periphery of the furnace. Lowering the stockline below 1·3 m. led to greater thickness of the layers of ore at the furnace periphery, while the ridge of fines approached the walls of the furnace. A lower stockline also resulted in better gas distribution, the CO_2 content of gas increasing at the periphery and decreasing at the centre of the furnace. These results show that variation of stockline level provides an additional method of controlling blast-furnaces. The best level at which the stockline of a given furnace should be maintained must be determined empirically.—S. K.

The Relation between the Specific Capacity of the Blast-Furnace and Its Coke Consumption. F. Wesemann. (Stahl und Eisen, 1948, vol. 68, Jan. 1, pp. 1–8). Process statistics for the production of pig iron in the Ruhr district are evaluated and compared with data from the districts of South Germany and the Saar. Whilst the coke-consumption in the Ruhr blast-furnaces is much higher than in the other districts, the "specific capacity" (coke throughput in kg./sq. m. of shaft cross-section/hr.) and the flue-gas temperatures are also much higher, and the proportion of indirect reduction and "shaft energy" (amount of volatile matter, CO_2, and moisture in the flue gas in kg./ton of pig iron) are lower. The data from the Ruhr furnaces showed that the specific capacity had an important effect on both the flue-gas temperature and the indirect reduction as well as on the coke consumption. A reduction of the coke throughput in the Ruhr basic-iron furnaces should result in an appreciable reduction in the coke consumption independent of the percentage of iron produced from the burden. The relationships between shaft energy, scrap in the charge, and the amount of slag, as well as the significance of the oxygen fixed by the iron and other elements in the burden and its relation to the scrap and remelted iron are examined.

The evaluation brings out the importance of improving as much as possible the flow of gas through the furnace, the reaction capacity of the burden, the efficiency of the heating coke, and the proportion of indirect reduction. The importance of continuously evaluating process statistics is stressed.—R. A. R.

Experiments with Explosives for Opening Furnace Tap Holes. (Steel, 1948, vol. 122, Feb. 16, pp. 107–110). This is a report of a meeting of the Eastern States Blast Furnace and Coke Oven Association on Feb. 6, 1948, at which J. R. Barns described a "jet caster" method of opening the tap hole of a blast-furnace. This consists of firing a 12 in. × 2-in. dia. cartridge containing 2 oz. of explosive in a previously drilled 2¼-in. hole. Blast-furnace linings, carbon hearths, and the burning of tuyeres were also discussed.—R. A. R.

Economic Considerations for Stack Lining Repairs. W. R. Trognitz. (Eastern States Blast Furnace and Coke Oven Association : Steel, 1948, vol. 122, Mar. 1, pp. 110–112 ; Blast Furnace and Steel Plant, 1948, vol. 36, Mar., pp. 322–324). The condition of the lining of a large blast-furnace at the time repairs were carried out is described, and details are given of the improved production and lower coke rate obtained after renewing parts of the lining.—R. A. R.

The Stürzelberg Process for Manufacturing Pig Iron. (British Intelligence Objectives Sub-Committee, 1948, F.I.A.T. Final Report No. 1062 : H.M. Stationery Office). The production of a high grade of pig iron from a low grade of ore by a batch process in a short rotary kiln is described. This, the Stürzelberg process, was discussed by F. Eulenstein and A. Krus (*see* Journ. I. and S.I., 1937, No. I, p. 158A). It may be used with advantage on ores containing considerable quantities of other metal oxides which are difficult to deal with in a blast-furnace.—R. A. R.

Causes of The Refining Properties of Calcium Silicide on Cast Irons. C. Bordoni. (Annali di Chimica Applicata, 1947, vol. 37, Oct.–Nov., pp. 412–416 : [Abstract]. Chimie et Industrie, 1948, vol. 59, Apr., p. 366). Chemical, mechanical, and metallographic tests, carried out on specimens of cast iron treated with calcium silicide, show that it reacts on the molten iron with the following effects : (1) Reduction of carbon monoxide and increase in temperature which destroys the primary graphite and liberates finely divided and active carbon, due to the decomposition of ledeburite and austenite into pearlite and graphite ; (2) taking into consideration the increased heat due to the preceding reaction, a reduction of FeO and MnO is observed ; and (3) finally, if the temperature is favourable, lime, liberated during the first reaction, and calcium silicide lead to desulphurization, with absorption of heat. The refining of cast iron by calcium silicide must be carried out at a temperature

of over 1350° C., and the optimum quantity is 0·3% for normal melting.

PRODUCTION OF STEEL

Progress in the Polish Iron and Steel Mechanical Industries. F. Marle. (Génie Civil, 1948, vol. 125, Apr. 1, pp. 134–135). The present position of the Polish iron and steel and engineering industries is briefly surveyed.—R. F. F.

Metallurgical Industries of India. (Echo des Mines, 1948, Jan., p. 13). The present position of India's metallurgical industries is briefly described.—R. F. F.

Former Wasteland Now Western Steelmaking Enterprise. G. E. Stedman. (Steel, 1948, vol. 122, Mar. 8, pp. 128–138). An illustrated description is given of the integrated iron and steel works at Geneva, Utah, with details of its post-war production since it was acquired by the United States Steel Corporation in 1946.—R. A. R.

Future Prospects of the Iron and Steel Industry in South America. (Echo des Mines, 1948, Jan., p. 13). Plans for developing the iron and steel industries of Brazil and Chile are described.—R. F. F.

A Comparison of the Two Basic Processes of Steel Making. H. F. Padbury. (Proceedings of the Ebbw Vale Metallurgical Society, 1947–48, vol. 1, pp. 46–58). The Bessemer and open-hearth processes of steelmaking are compared and data on the two processes as practised in Great Britain, the United States, and Germany, are given.—R. A. R.

Developments in the Construction of Open-Hearth Furnaces. J. Alexandrovsky. (Hutnické Listy, 1948, vol. 3, No. 2, pp. 33–37 ; No. 3, pp. 72–78). [In Czech]. The developments which have taken place in the design of open-hearth furnaces in the chief steel-producing countries are reviewed, and recommendations for the design of new furnaces, based on experience gained, are made.—R. A. R.

Some Questions Concerning the Improvement of Open-Hearth Furnace Construction. D. A. Smoliarenko and N. I. Efanov. (Stal, 1948, No. 1, pp. 18–27). [In Russian]. An account is given of experiments made on the functioning of an open-hearth furnace with Venturi ports, such as is widely used in the U.S.S.R. The following observations were made : (1) The flame temperature reached a maximum of 1830° C. opposite the second charging door. (2) The ratio of the amount of burnt gases passing through the gas regenerator to that passing through the air regenerator had a maximum value of about 0·44, and the respective maximum checkerwork temperatures were 950° and 1170° C. (3) The distribution of pressure, temperature and gas-velocities in the various parts of the furnace were determined : the results are shown in diagrams, and in this connection the effect of several types of valve is described.

Some dimensions of Venturi ports in use in the U.S.S.R. are given, and comparisons are made between the functioning of this and other types of port. The specifications of refractories for use in open-hearth furnaces are discussed and the following figures are given for a satisfactory type : mechanical strength, 254 to 350 kg./sq. cm. ; porosity, 22·4% ; refractoriness, 1730° C. ; alumina-content, 45·33%.—S. K.

Open-Hearth Furnace Models. A. R. Philip. (Nature, 1948, vol. 161, Mar. 27, p. 479). Models of open-hearth furnaces have been made in Perspex on a 1/24 linear scale to study the flow of air and gas by photographing streams of a suspension of aluminium particles in water passing through the model. A study of a model of a Maerz open-hearth furnace indicated : (1) At the incoming end a major vortex is produced on either side of the incoming gas stream over a wide range of flow ; (2) in the centre of the furnace there is a region of instability in which the particles are moving in all directions ; and (3) near the outgoing end the flow tends to align itself before entering the outgoing ports, and is particularly rapid along the back wall.—R. A. R.

The Deoxidation of Steel by Diffusion. K. K. Chuprin. (Stal, 1948, No. 2, pp. 135–142). [In Russian]. After a discussion of the various diffusion-deoxidation processes in use, experiments are described in which coke was used to deoxidize steel in the basic open-hearth process. The experiments were carried out in 100-ton open-hearth furnaces, an average of 4 kg. of coke being used per ton of steel, together with a small quantity of ferro-silicon. The coke, in 1–5-mm. pieces, was evenly distributed over the whole bath, 2–3 kg./ton of steel being applied as soon as the desired carbon content had been attained, and the rest not later than 10 min. before tapping. Slag and metal samples were taken from the furnace before and after deoxidation, and also during casting. The properties of the steel are compared with those of steels produced with the usual deoxidizers, the use of coke being shown to lead to considerably superior mechanical properties, to have no effect on the phosphorus and sulphur contents, and to reduce by a half and two thirds the oxidation of manganese and silicon respectively, no oxidation of chromium being observed. No technological difficulties arose from the use of coke. The theory of the process is discussed.—S. K.

An Analytical Method for the Calculation of the Thermal Conditions in the Open-Hearth Furnace. M. A. Glinkov. (Stal, 1948, No. 2, pp. 126–144). [In Russian]. An analytical method is proposed whereby it is possible to calculate the output of any open-hearth furnace melting a standard charge without the necessity of compiling a detailed heat balance. Many operating factors, such as the calorific value of the fuel, the nature of the flame and the speed of charging, are included in the scope of the method. Calculations for non-standard charges are only possible if their equivalent coefficients of thermal conductivity are known.

The total expenditure of heat for melting is represented by an equation the terms of which include the differentials, with respect to time, of the change in temperature resulting from the chemical reactions and of the heat required for the useful work of heating and melting ; it is with the evaluation of these two terms that the method is especially concerned. The standard-charge concept on which the method is based, involves a schematic arrangement of the lime, ore and metallic parts of the charge in the furnace ; the mean composition of the standard charge and the rate of charging being those of actual practice. By making certain assumptions, operation with liquid charges can be brought into the scope of the standard-charge concept. Conventions are also adopted regarding the thermal capacities of the charge and melt. The following factors are dealt with on the above basis : (1) The equivalent coefficient of thermal conductivity of the charge and melt ; (2) the integral coefficient of heat-transfer ; (3) the temperature distribution in the charge and molten bath ; (4) changes in the heat content of the charge during heating ; (5) changes in the heat content of the slag and molten metal ; and (6) the equation for the heat required.

As an example of the applications of the method, the output of and the thermal conditions in an open-hearth furnace with the following characteristics are calculated : Hearth area, 30 sq. m. ; capacity, 64 tons of liquid metal ; calorific value of gaseous fuel, 2000 cal./cu. m. ; a product containing carbon 0·30%, manganese 0·45%,

and traces of silicon ; a charge containing carbon 2·0%, manganese 0·95%, and silicon 0·55% ; expenditure of lime and ore, 5% and 8% respectively of the weight of the metallic part of the charge.—S. K.

Basic Ends and All-Basic Open Hearth Furnaces. R. P. Heuer and M. A. Fay. (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 47–60). The history of the development of basic ends and basic roofs for open-hearth furnaces is presented with particulars of (*a*) the designs adopted ; (*b*) comparative costs of basic and silica ends and basic and silica roofs, (*c*) analyses, quantities ; and values of the slags formed, and (*d*) time saved in rebuilding basic ends as compared with silica ends. Savings of from $0·10 to $0·25 per ton of steel can be obtained with basic ends, and the results obtained with the all-basic furnace are extremely promising.—R. A. R.

The Utilization of Manganese in the Basic Open-Hearth Process. (Stahl und Eisen, 1948, vol. 68, Mar. 25, pp. 123–124). In correspondence W. Krauskopf refers to H.-J. Krabiell's method of evaluating the factors affecting the utilization of manganese in steelmaking (*see* Journ. I. and S.I., 1948, vol. 158, Mar., p. 397), and points out cases where his own observations are not in agreement with Krabiell's evaluation. H.-J. Krabiell replies pointing out certain differences in the working of the heats.—R. A. R.

Note on Further Work on the Phosphorus Reaction in Basic Steelmaking. P. Vajragupta. (Journal of the Iron and Steel Institute, 1948, vol. 158, Apr., pp. 494–496).

Bunched Open Hearth Heats and Suggestions for Their Prevention. R. K. Harris. (Blast Furnace and Steel Plant, 1948, vol. 36, Feb., pp. 205–211). An examination is made of the tendency of open-hearth heats to " bunch " together, *i.e.*, to be ready for tapping at about the same time, resulting in congestion and the disturbance of routine in various other departments and processes. Suggestions for the avoidance or minimizing of the tendency are outlined.—J. R.

First Results of the Use of Oxygen in Steelworks. F. Kerry. (Société Française de Métallurgie, 6 June, 1947 : Revue de Métallurgie, 1947, vol. 44, Sept.–Oct., pp. 278–285). Preliminary tests on the use of oxygen in an oil-fired open-hearth furnace of the Steel Company of Canada are described. The design of the burner, the oil consumption, the furnace dimensions, the consumption of oxygen and its purity, the charging conditions for scrap, the effect on roofs, and the use of this process in different types of furnaces are discussed. Results show that the production of steel increases by an average of 50%, whilst the fuel consumption is lowered from 25 gal. (Imperial) per ton to 18 gal. per ton of steel produced. The use of oxygen for refining steel is then discussed. Oxygen is passed through the molten metal, using a lance at least $\frac{5}{8}$-in. in inside dia., which is plunged 2 in. under the slag. In this way the carbon content can be brought down to 0·04%. The refining operation is easy to control and a useful saving in fuel is obtained as well as a reduction of $\frac{1}{2}$ hr. in the heat time. The use of argon for the removal of hydrogen is also mentioned.—R. F. F.

Oxygen Uses in Steel Production. J. H. Zimmerman. (Iron and Steel Engineer, 1948, vol. 25, Feb., pp. 35–44). Operating data and experience resulting from the use of high-purity oxygen during the course of over 6000 open-hearth heats in some 34 steelplants are discussed and summarized. The two main applications are the oxygen lance or jet for decarburization, and the enrichment of combustion air, mainly in liquid-fuel-fired furnaces, for melting down scrap.—J. R.

The Use of Oxygen in Open Hearth Furnaces. E. C. McDonald. (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 37–43). Operating data on the use of oxygen for 770 heats in a 200-ton open-hearth furnace are presented and discussed. Drawings of the injection devices are shown. The experience gained leads to the following conclusions : (1) The heat time is shortened and the fuel consumption per ton of steel is reduced ; (2) with charges of 80% hot metal and 20% scrap the greatest benefit is derived by oxygen injection to eliminate carbon ; (3) if full advantage can be taken of fast melting down, the advantage of bath injection over supplying oxygen to the burner diminish with increasing proportions of hot metal ; (4) burner-injected oxygen increases the luminosity of the flame and promotes quicker melting ; (5) introducing oxygen-enriched air into the chequers does not affect the flame so much as supplying oxygen to the burner ; (6) a better method of introducing oxygen into the bath so as to maintain the life of the roof must be found ; (7) the discharge of dust from the stack while using the oxygen lance can be prevented by water scrubbing ; and (8) oxygen of lower purity could perhaps be used with advantage.—R. A. R.

The Use of Sponge Iron for Steel Production in Sweden. M. Tigerschiöld and S. Eketorp. (Metallurgia, 1948, vol. 37, Feb., pp. 167–177). This paper is based on M. Tigerschiöld's address " The Use of Sponge Iron in Swedish Steel Production " (*see* Journ I. and S.I., 1948, vol. 158, Jan., p. 151) and a lecture by S. Eketorp, They describe the Höganäs and Wiberg processes and give full data on the economic aspects.—R. A. R.

Electric Hot Topping Steel Ingots. E. S. Kopecki. (Iron Age, 1948, vol. 161, Mar. 25, pp. 80–86). The equipment and process for keeping the tops of ingots hot by electricity and thus reducing pipe are described. A movable bracket holds a liquid-cooled non-consumable electrode submerged in a flux on top of the ingot. The electrode weighs about 23 lb. and the power required is about 20 kWh./ton of ingots. Experience indicates that an increase in yield of 4% from ingot to billet is obtained.—R. A. R.

A New Type of Rapid-Charging Arc Furnace. (Journal du Four Electrique, 1947, vol. 56, Feb.–Mar., pp. 10–11). Top-charging 8–10-ton arc furnaces, with swivelling roofs, built by the Société Alsthom to the design of the Société Générale d'Applications Electro-Thermiques, are described. Melting takes $1\frac{3}{4}$ to 2 hr. and the whole operation $3\frac{1}{2}$ to 5 hr. according to the duration of refining, with a power consumption of 650 to 750 kWh./ton of steel. The daily average is five melts and the daily average production is approximately 50 tons. These furnaces give good results for the manufacture of low-carbon stainless steels.—R. F. F.

The Thermochemical Behaviour of Chromium in the Manufacture of Electric Steels. A. Bargone. (Técnica Italiana, 1947, vol. 2, No. 1, pp. 17–22 : Chemical Abstracts, 1948, vol. 42, Mar. 10, p. 1513). This is a review of the rôle of chromium in electric steel manufacture. With the aid of thermochemical data the mechanical characteristics of steel castings with low and high chromium contents are discussed.

Electrolytic Manganese in Acid and Basic Electric Steel Foundry Practice and Basic Steel Ingot Production. F. Sillers, jun., R. T. C. Rasmussen, and J. H. Jacobs. (United States Bureau of Mines, 1947, Dec., Report of Investigations No. 4157). An account is given of tests in the use of electrolytically produced manganese in steelmaking. These confirmed that this manganese is just as good technically as ordinary grades of ferro-manganese, but the cost is greater. The percentage

of manganese recovered in basic practice was 90% to 100%. In acid practice the recovery was about 65%. —R. A. R.

Buffer Set for Supply to Steel Furnaces. (Electrical Times, 1948, vol. 113, Mar. 25, pp. 359–361). A description is given of the 3600 h.p. synchronous motor alternator set which has been installed at Letchworth, to smooth out the load on the turbo-alternators supplying current to a system where two 5-ton electric-arc steel furnaces have recently been put in commission.—R. A. R.

The Effect of Gases on the Solidification of Ingots. I. V. Polin. (Stal, 1948, No. 1, pp. 55–59). [In Russian]. To investigate the effects of gases on solidification phenomena in ingots, standard melts of steel were de-gassed *in vacuo* and then saturated with the appropriate gas or gas mixture. After solidification in moulds of rectangular cross-section, the ingots were cut longitudinally and their macro-structure was examined. The steel used had the following composition: C 0·2–0·35%; Mn 0·2–0·3%; Si 0·2–0·3%; S $\leqslant$ 0·04%; P $\leqslant$0·05%. The gases were air, hydrogen, nitrogen, steam, and nitrogen-steam mixture. In one case the solidification was carried out *in vacuo*. Hydrogen was found to have the greatest effect on the solidification, and the following conclusions are drawn from the experiments: Steel which is almost hydrogen-free does not develop dendritic crystals under any conditions of casting; there are minimum and maximum limits of hydrogen content within which a roughly dendritic structure is developed, and, having determined these limits and the degree of hydrogen segregation for a particular steel, it is possible to calculate the extent of the various zones in the ingot; the ingot structure depends on the surface energy of crystallization, and can thus be altered by the addition of suitable ingredients.—S. K.

PRODUCTION OF FERRO-ALLOYS

The Production of Ferro-Alloys in the Electric Furnace and Its Consequences for the Steelmaker. H. Werwach. (Stahl und Eisen, 1948, vol. 68, Jan. 1, pp. 8–14). Conditions in Germany make it essential to economize in the consumption of electricity. The production of ferro-alloys is examined from this point of view. The percentage of alloying element passing into the metal is much higher when making alloy steel in the arc furnace than in the open-hearth furnace. The high-frequency furnace is particularly suitable for remelting high-silicon steels.—R. A. R.

Smelting Ferromanganese with the Minimum Coke Consumption. I. Z. Kozlovich. (Stal, 1948, No. 1, pp. 11–14). [In Russian]. The usual practice of smelting ferromanganese in blast-furnaces near the end of their campaigns leads to waste of coke and makes the subsequent relining of the furnace more expensive. Efficient ferromanganese production has been achieved by the use of a special blast-furnace with carbon-brick-lined well, hearth, and bosh. The furnace had the following dimensions: Diameters of hearth, bosh, and throat, 4500, 6800, and 4790 mm., respectively; heights of hearth, bosh, and cylindrical part of bosh, 1800, 4500, and 1127 mm., respectively; effective stack height, 17,340 mm. The stack was cooled by cast-iron plate coolers and the hearth below the tuyeres by external spray. Water at 5 atm. pressure was sprayed in the throat both for cooling and to minimize the considerable dust-loss which occurs during the smelting of ferromanganese.

Owing to the high blast temperature (over 900° C.) special care was given to the three Cowper stoves, an extra battery being included in the electrostatic gas-cleaning plant, and each stove was thoroughly overhauled after 20 days' operation.

The coke, which was crushed and screened, contained 8–10% of ash, 3% of moisture and about 0·5% of sulphur. All the lime was sized to 100–120 mm. The consumption of materials for a week was as follows: Ore containing manganese 50–51% 2626 tons, ore containing manganese 47–48% 1066 tons, iron ore containing iron 46–47% and manganese 8–9% 448 tons, lime 921 tons, flue dust about 75 tons, and coke 2544 tons. The total weight of ferromanganese produced during this period was 1764 tons, 915 tons of which was 78–80%, 392 tons 80–82%, and the rest 76–78%. The mean coke-rate for the process was thus about 1·5. The contents of silicon, phosphorus, and sulphur in this ferromanganese were 0·44–1·42%, 0·30%, and 0·014–0·017%, respectively. In spite of the basic burden used, the average manganese in the slag was 16·82%; of the total manganese in the burden, a further 7% was lost in the flue-dust, and hence only about 76% of the available manganese found its way into the ferromanganese.—S. K.

Calcium Carbide and Ferro Alloy Production in Italy. G. Zuliani. (Journal du Four Electrique, 1948, vol. 57, Jan.–Feb., pp. 3–6). The present position of the calcium carbide and ferro-alloy industries in Italy is described. —R. F. F.

FOUNDRY PRACTICE

The Design of Gravity-Fed Castings in Metal Moulds. H. Portier. (Association Technique de Fonderie, 17 Dec., 1943). Factors which affect the design of castings, such as the choice of metal, and the minimum thickness compatible with the size and purpose of the casting, are discussed.—J. C. R.

Tolerances in the Production of Grey Iron Castings. V. Jareš. (Hutnické Listy, 1948, vol. 3, No. 3, pp. 66–72). [In Czech]. Shrinkage and other allowances which are applied when making patterns for grey iron castings are discussed.—R. A. R.

Current Melting Problems in the Gray Iron Foundry. D. J. Reese. (Foundry, 1948, vol. 76, Mar., pp. 78–79, 184–188). Methods of adjusting cupola charges to suit the changes in the availability of pig iron and scrap are discussed and recommendations for more economical workings are made.—R. A. R.

General Considerations on Fuel Efficiency in Melting Shops. (Fonderie Belge, 1947, July–Aug., pp. 17–22: [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Feb., p. 16). Amongst the factors considered in order to effect fuel economies, are: Co-ordination of casting operations so that the moulds are ready to receive the metal as soon as it has been melted; calculation of the exact quantity of metal required, to avoid wastage; insulation and maintenance of furnaces; refractory bricks to be kept dry; and coke to be handled as little as possible. Fuel economies that can be effected with cupolas, reverberatory furnaces, crucible furnaces, rotary furnaces, and electric furnaces are reviewed.

Economic Production of Cast Iron by High Superheating and Direct Refining in the Cupola. G. Itam. (Association Technique de Fonderie, 6 Mar., 1941; Bulletin de l'Association Technique de Fonderie, 1941, Nov.–Dec., pp. 108–118). The author describes in detail his investigations on the superheating of iron up to 1625° C. in the cupola, giving analyses of the materials charged and the composition and mechanical properties of the iron obtained. The paper is critically reviewed by G. Hénon in the discussion.—J. C. R.

Cupola Charge Calculations. R. W. Heine. (Foundry, 1948, vol. 76, Feb., pp. 89, 172–176). A method of

calculating the cupola charge to produce iron of a given chemical analysis is described with examples.—R. A. R.

Desulphurizing with Soda Ash. W. W. Levi. (Foundry, 1948, vol. 76, Apr., pp. 78, 176–186). The soda-ash desulphurizing practice at a large foundry with four 72-in., two 60-in., and one 48-in. dia. cupolas is described. Blocks of fused soda ash and three times the normal amount of limestone are charged so as to provide a large volume of fluid slag at an early stage of the heat; soda ash is also added to the fore-hearth down a chute to the point where the molten metal is poured in.—R. A. R.

Production of Dephosphorized Iron by Blowing without Decarburization. L. F. C. Girardet. (Bulletin de l'Association Technique de Fonderie, 1940, Mar.–Apr., p. 38). A summary is presented of a paper in which the author considers the use of blast containing carbon monoxide in the form of blast-furnace or producer gas, in a basic-Bessemer converter to dephosphorize the iron without decarburizing it.—J. C. R.

Remelting Iron without Special Coke, or with Crude Fuels such as Wood, Coal, etc. L. F. C. Girardet. (Bulletin de l'Association Technique de Fonderie, 1940, Mar.–Apr., pp. 38–39). A summary is presented of a paper in which the author outlines the results of melting iron in a very small experimental cupola in which the fuel and the iron were kept separate. It is proposed to build a small industrial unit of the same type.—J. C. R.

Recommendations for the Design of High-Tensile Cast Steel Structures. J. Galibourg. (Bulletin de l'Association Technique de Fonderie, 1940, May to 1941, Oct., pp. 68–75). The author outlines some recommendations for the desirable tensile and elastic properties of high-tensile cast steel shapes. Difficulties that arise in foundry practice and means of overcoming them are discussed. The steels dealt with are of the self-hardening chromium–nickel and chromium–molybdenum–nickel types.—J. C. R.

Pressure Feeding of Steel Castings. W. T. W. Shute. (American Foundryman, 1948, vol. 13, Feb., pp. 60–62). Recommendations are made for the design of gates and risers for steel castings and an example is given of the reduction in the cavities obtained in a cast column of steel 30 in. high by allowing atmospheric pressure to act on the riser.—R. A. R.

Foundry Sands. F. Girardet. (Association Technique de Fonderie, 21 May, 1943). After tracing the history of foundry sands, the author deals with their present-day applications in foundry practice. Among the aspects which he considers are their properties, permeability, size classification, binding agents, the action of water on the constituent elements of sands, reclamation of sands, core sands, synthetic sands, and refractory facing coatings.—J. C. R.

Bentonites and Clays from the Foundryman's Point of View. P. Dauxois. (Bulletin de l'Association Technique de Fonderie, 1944, July–Dec., pp. 44–56). When moulding sands are reclaimed the ordinary clay contained in them is progressively replaced by bentonites or selected clays. Data on the physical properties of these clays is insufficient to determine their value in the foundry. Direct tests have accordingly been carried out to determine a series of curves of constant cohesion as a function of the water content and the composition of the sand, which will indicate the properties of the mixture. The results obtained are analysed and the uses to which the graphs can be put are discussed.—J. C. R.

Reclamation of Foundry Sands. L. F. Girardet. (Bulletin de l'Association Technique de Fonderie, 1942, Apr.–June, pp. 27–30). An account is given of methods for the reclamation of burnt foundry sands, *i.e.*, those which have been in contact with the metal. Wet and dry methods for dedusting the sand and for adding clay as a binding agent are outlined.—J. C. R.

Malleable Sand Control. D. Tamor. (American Foundryman, 1948, vol. 13, Feb., pp. 50–51). The merits of naturally bonded and synthetic moulding sands are compared. A mixture of 10% of the former with the latter gives a very good grain distribution. When planning a mechanized system of sand reclamation it is essential to have ample hopper capacity so that the sand has time to cool before it comes back to the moulder.—R. A. R.

Foundry Sand—Uncontrolled. H. E. Henderson. (Foundry, 1948, vol. 76, Apr., pp. 95, 230–236). The author, in relating his experience with the problems of green sand and dry sand in foundries, points out that full control of the sand is never achieved.—R. A. R.

Green Sand for Steel Castings. K.-G. Sandström. (Jernkontorets Annaler, 1948, vol. 132, No. 3, pp. 59–90). [In Swedish]. The results of laboratory investigations of the properties of green sand for steel castings are reported. The main purpose was to study how the strength and permeability were affected by the percentages of moisture and binder, and by the lapse of time after ramming. The sand mixtures consisted of crushed sandstone and one of the following binders: cereal binder, dextrine, sulphite lye, waterglass, fine resin, and bentonite. Very high permeability values were obtained with sulphite lye, cereal binder, and dextrine. The permeability when using bentonite can be increased by adding one of the above three binders. The compressive strength 30 sec. after ramming was quite low in all cases, but after 24 hr. it was quite high for all binders except resin and bentonite. Dextrin and sulphite lye gave the highest compressive strengths. These conclusions are based on tests at room temperature. In tests with baked sands, dextrine gave a very high strength 30 sec. after ramming, and it had good moulding properties with a low moisture content, but a lot of gas is given off. An addition of bentonite increases the strength of a dried dextrin-bonded sand 30 sec. after ramming. Sulphite-lye-bonded sand is not so easily moulded as dextrine-bonded sand.—R. A. R.

The Use of Fullers' Earth in Foundries. L. V. Roy. (Institute of British Foundrymen: Foundry Trades Journal, 1948, vol. 84, Mar. 18, pp. 271-274). The four principle uses of Fullers' earth in foundries are discussed. These are: (1) For bonding synthetic moulding sands; (2) for strengthening natural moulding sands, (3) for semi-synthetic sands; and (4) as a coarse sand binder in conjunction with an organic binder.—R. A. R.

Synthetic Resin Binders—Application in the Foundry Industry. H. C. Frisbie. (American Foundryman, 1948, vol. 13, Feb., pp. 37–39). The use of synthetic-resin core binders is discussed. Phenol-formaldehyde dry core binder is the best type for grey iron and steel castings. Its advantages are enumerated.—R. A. R.

Modern Foundry Theory for the Patternmaker. E. J. McAfee and R. G. Wagner. (American Foundryman, 1948, vol. 13, Feb., pp. 52–56). The theory of the use of open-top and blind risers is explained and examples are shown of the way in which minor changes in design can be applied to eliminate shrinkage cavities.—R. A. R.

Internal Risers. A. Bichler. (Hutnické Listy, 1948, vol. 3, No. 2, pp. 41–43). [In Czech]. Experiments with internal risers at a Czech foundry produced results differing from those in Canadian foundries. The sand between the casting and the internal riser conducted very little heat, and the removal of the risers presented great difficulty.—R. A. R.

Internal Risers on Steel Castings. T. Shute. (American Foundrymen's Association: Foundry, 1948, vol. 76, Feb., pp. 82–83, 236). The advantages and disadvantages of internal risers on steel castings are considered with some illustrated examples.—R. A. R.

Moulding Machines. R. Guérin. (Bulletin de l'Association Technique de Fonderie, 1942, July–Sept., pp. 34–42). The author discusses the ramming of sands for moulds and gives illustrated descriptions of various types of moulding machines, including the jolt-ramming type. Methods of stripping the mould are also outlined. —J. C. R.

Moulding and Casting in Cement-Sand. H. Achatz. (Metalen, 1948, vol. 2, Apr., pp. 165–171). [In Dutch]. Examples of cement-sand moulding and casting in a jobbing foundry making castings up to 40 tons are described.—R. A. R.

Core-Blowing Machines. H. Prévost. (Bulletin de l'Association Technique de Fonderie, 1943, Apr.–June, pp. 18–31). The author states that core-blowing machines can be used for small and medium as well as large articles. The following points are examined: Operational principles of blowing machines; various types of machines; detailed description of a particular machine; the sand; filling the core box; organization of the work; and research work on better means of compression.—J. C. R.

Steel Foundry Uses Wood Plate on Core Blower. P. Dwyer. (Foundry, 1948, vol. 76, Mar., pp. 82–84, 224–232). The use of wooden plates on core boxes for core blowing is discussed with notes on the number, size, and distribution of holes and vents.—R. A. R.

The Baking of Foundry Cores. (France Énergétique, 1947, vol. 6, May–Aug., pp. 99–100: [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 18). The technique of continuous drying of foundry cores in horizontal and vertical ovens is explained and reference is made to drying in small movable ovens.

Fuel Economy in Foundry Ovens. G. Hénon. (Bulletin de l'Association Technique de Fonderie, 1944, Apr–June, pp. 17–32). The author first reviews the object and mechanism of drying moulds in foundry ovens and then discusses the heating of the ovens by solid and liquid fuels, by gas or electricity, or by the use of recovered waste heat. A balance sheet of the heat produced and consumed, and the sources of loss are outlined. A bibliography of 64 references is appended.—J. C. R.

Drying Stopper Rods at American Steel Foundry. (Industrial Heating, 1948, vol. 15, Jan., pp. 112–113). A description is given of an oven for drying ladle stopper rods. The oven is 6 ft. wide, 10 ft. 6 in. high and 20 ft. long, and it can accommodate 65 8-ft. stopper rods at a time.—R. A. R.

The Conversion of Foundry Ovens to Solid Fuel. A. I. Vashchenko. (Stal, 1948, No. 2, pp. 173–176). [In Russian]. The use of solid fuel for drying cores at a foundry in Moscow is described and details of the stove and burners are given. Some designs for horizontal and vertical conveyor-type stoves are considered.—S. K.

The Production of the Main Parts of Machine Tools in the Iron Foundry. L. Prévost. (Association Technique de Fonderie, 8 May, 1940). An account is given of the various factors that have to be taken into consideration when the principal parts of machine tools are produced in the iron foundry. Particular reference is made to internal stresses and means of relieving them.—J. C. R.

Molding Sheaves in Dry Sand Cores. W. Pink. (Foundry, 1948, vol. 76, Apr., pp. 88–89). The moulding technique of making the hubs and rims of large sheaves for pithead winding gear is described.—R. A. R.

Multiple Molding Can Increase Production. W. G. Gude. (Foundry, 1948, vol. 76, Mar., pp. 67–68, 198–200). A foundry technique for producing large numbers of small or shallow castings is described. The principal feature is that as many as ten flasks can be paced in a single stack with a common sprue through the centre, and the metal flows from the sprue through runners to the casting cavities in each flask. The advantages and limitations of the method are discussed.—R. A. R.

Manhole Covers. A. R. Parkes. (Foundry Trade Journal 1948, vol. 84, Mar. 18, pp. 275–276). A brief description is given of the plant and processes at the foundry of the Dover Engineering Works, where cast-iron manhole covers are made.—R. A. R.

Foundry Parting Compounds. H. Brown. (Foundry, 1948, vol. 76, Feb., pp. 74–75, 114, 117). The properties of parting compounds and methods of testing them are discussed.—R. A. R.

The Development and Present Condition of the Continuous Casting of Metal. I. Ya. Granat and V. M. Tageev. (Stal, 1948, No. 2, pp. 160–166). [In Russian]. A short note on the history of continuous casting is followed by descriptions of the various processes now in use.—S. K.

Precision Castings in High-Melting Point Alloys for General Engineering Purposes. F. Hudson. (Midland Metallurgical Societies: Metallurgia, 1948, vol. 37, Mar., pp. 243–247). The factors affecting the economic aspects of the precision casting of high-melting-point materials such as steel, nickel alloys, and cast iron, and possible new applications are discussed. To reduce the cost of special castings it is recommended that the production of components required in large quantities should be developed so as to spread the overhead charges and the cost of experimental work over a wider field.—R. A. R.

The Casting of Very Small Pieces in Stainless Alloys for Dental Settings. Possibilities of Application in the Ordinary Foundry. R. Chavy. (Bulletin de l'Association Technique de Fonderie, 1943, Oct.–Dec., pp. 49–55). The author discusses the mechanical and physical properties required in stainless alloys used in dental work. Stainless steels of the 18/8 type, preferably with molybdenum and titanium additions, give good results but present casting difficulties. Unless molybdenum and titanium are present, carbides may be precipitated when the metal is cooling within the 400–500° C. range which can lead to corrosion. The method of casting such small pieces using the lost-wax process is described, and brief reference is made to the possibility of casting small parts for the automobile and aeronautical industries.—J. C. R.

Determinable Variations in Close Tolerance Castings. L. M. Nielsen. (Foundry, 1948, vol. 76, Feb., pp. 72–73). Data are presented on the variations in casting dimensions which may be expected when using metal patterns and wooden patterns due to differences in ramming, setting cores, drawing patterns by hand, and shift between cope and drag.—R. A. R.

New Electro Alloys Foundry in Production. (Industrial Heating, 1948, vol. 15, Jan., pp. 54–64, 164). A brief illustrated description is given of the newly equipped foundry of the American Brake Shoe Company. The melting shop comprises three induction furnaces melting 200, 1000, and 2000 lb./hr. and three arc furnaces melting 1000, 3500, and 10,000 lb./hr. respectively; there are also heat-treatment, X-ray inspection, and machining departments.—R. A. R.

Doubles Foundry Capacity with Same Floor Area. W. G. Gude. (Foundry, 1948, vol. 76, Apr., pp. 73–76, 118–120). The plant, layout, and processes at the

foundry of Link-Belt Co., Philadelphia, which now produces over 800 tons of grey iron castings per month, are described and illustrated.—R. A. R.

Produces Wide Variety of Iron and Nonferrous Castings. G. E. Stedman. (Foundry, 1948, vol. 76, Apr., pp. 92–94). Foundry practice, including centrifugal casting operations, at the foundry of Paxton-Mitchell Co., in Nebraska, are described.—R. A. R.

Old Foundry Has Face Lifted. P. Dwyer. (Foundry, 1948, vol. 76, Feb., pp. 76–78, 112–114). A description is given of the modern equipment and processes at the foundry of Alten's Foundry and Machine Works, Lancaster, Ohio, where three cupolas, 18 in., 36 in., and 48 in. in dia., respectively, are used.—R. A. R.

Grinding Wheels in the Foundry. G. Martin. (Bulletin de l'Association Technique de Fonderie, 1943, July–Sept., pp. 34–43). An illustrated account is presented of various types of grinding wheels used in the foundry for fettling castings, and of the motors used to drive them.—J. C. R.

Mechanical Handling—Feature of Redesigned Small Foundry. R. E. Crawford. (Canadian Machinery, 1947, vol. 58, Feb., pp. 67–72 : [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 18). A description is given of the mechanized plant of a foundry manufacturing brake shoes for railway wagons.

Handling Materials in the Foundry Yard. R. H. Herrmann. (Foundry, 1948, vol. 76, Mar., pp. 70–76). Many modern types of lifting and transport appliances for use in foundry yards are described.—R. A. R.

Cutting Foundry Costs with the Right Tool for the Job. D. S. Linton. (Foundry, 1948, vol. 76, Feb., pp. 84–86, 248–252). The author discusses the reduction of costs of using portable tools in foundries by correcting defects in the air conditions, maintaining pneumatic equipment at maximum efficiency, and the correct selection of the tool for a particular job.—R. A. R.

Foundry Costs and Cost Controls. C. E. Westover. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, Jan., pp. 22–25, 37). Costing and cost control for foundries are discussed. An example is presented of an overhead-charge-absorption curve for which the ordinates indicate the ratio of total cost to direct labour cost, and the abscissæ the percentage of full capacity at which the foundry is producing. It is shown how to apply the curve to calculate the profit or loss per unit produced at degrees of activity above and below the point at which all charges are met.—R. A. R.

ROLLING-MILL PRACTICE

Improved D-C Generators for Reversing Mills. C. Lynn and W. H. Burr. (Iron and Steel Engineer, 1948, vol. 25, Feb., pp. 45–55, 70). Constructional details of direct-current generators for flywheel reversing mill motor sets are described and illustrated, and electrical considerations are discussed. The advantages of laminated generator frames as compared with the usual solid design are outlined.—J. R.

Mill Motor Brake Standardization. (Iron and Steel Engineer, 1948, vol. 25, Feb., pp. 71–77). At the 1947 Annual Convention of the Association of Iron and Steel Engineers discussion on the effect on motor-brake design of the proposed new Association rating for mill motors was opened by A. H. Myles, and brake standardization was discussed by A. Cortelli. The effect of WR^2 on brake design was outlined by A. E. Lillquist.—J. R.

Manufacture of Mill Type Motors. C. B. Hathaway. (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 105–106). The design of the latest type of D.C. mill motors is discussed.—R. A. R.

The Problem of Roll Adjustment in Heavy Reversible Rolling Mills—An Application of the Amplidyne. M. H. Mathiot. (Revue d'Electricité et de Mécanique Alsthom, 1947, Apr.–June, pp. 16–31 : [Abstract]. Revue Universelle des Mines, 1948, Series 9, vol. 4, Apr., p. 310). After recalling the general arrangement of a heavy reversible rolling mill with adjustable rolls, the author shows the suitability of using Ward-Leonard systems for controlling the motors. These must ensure rapid starting and good braking, as the production of a rolling mill depends, mainly, on the time taken by reversing. The suitability of the Ward-Leonard system is increased by the use of an amplydine as generator exciter. (The amplydine is a slightly improved version of the Rosenberg dynamo with the brushes magnetically aligned at 90°). The electrical adjustment equipment of the reversible plate mills of the Fabrique de Fer de Charleroi is described.

Maintenance Methods Symposium—Mill Bearings and Lubrication. F. B. Golley. • (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 91–93). The life of rolling-mill bearings, mainly of the synthetic-resin type, is discussed in the light of experience by the International Harvester Company.—R. A. R.

A Rational Shape for Slabs. I. D. Koozema. (Stal, 1948, No. 1, pp. 46–50). [In Russian]. Losses of metal of 3–4% of the weight of the slab occur when sheet is made by rolling slabs of the usual shape. These losses are mainly due to the fact that the sheets are not rectangular, and partly to the sheets having lapped edges as a result of the shorter sides of the cross-section of the slab being slightly concave. Such losses of metal can be reduced by keeping the value of the ratio (width of sheet)/(width of slab) below 2·5, and by the use of a rational shape of slab. Mathematical examination of the problem leads to equations for this rational shape from which it can be seen that the slab should have convex broad faces and narrow faces which are either flat or slightly convex.—S. K.

The Rolling of Broad Flanged Beams in Germany. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1678 : H.M. Stationery Office). Descriptions are given of three German rolling mills capable of rolling beams with broad parallel flanges. One, owned by Ilsider Hütte, was specially designed for rolling beams from 180 × 180 mm. to 100 × 300 mm. The other two are of conventional type, modified for this purpose.—R. A. R.

New Precision Light Section Rolling Mill. (Metallurgia, 1947, vol. 37, Dec., pp. 64–66). **Special Sections.** (Iron and Steel, 1948, vol. 21, Jan., pp. 9–13). The new rolling mill of Darlington and Simpson Rolling Mills, Ltd., is described. (*See* Journ. I. and S.I., 1948, vol. 158, Jan., p. 153).—R. A. R.

The Production of Ship Armour in Italy. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1670 : H.M. Stationery Office).

Fontana Increases Rolling Mill Facilities. J. M. Hooper. (Blast Furnace and Steel Plant, 1948, vol. 36, Feb., pp. 197–204). Rolling-mill developments completed or in progress at the Fontana plant of the Kaiser Company, Incorporated, are described. These comprise a 110-in. plate mill, a 36-in. blooming mill, a 29-in. structural mill, a 14-in. merchant mill, an 18-in. skelp mill, a continuous weld pipe mill, and a cold strip mill.—J. R.

The Y-Mill—A New Type of Cold Strip Mill. A. B. Montgomery and W. M. McConnell. (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 99–104). An illustrated description is given of a new type of reversing cold strip mill consisting of seven rolls in Y-formation. There is a V-shaped group of five rolls directly above

the lower work roll. The bottom roll of the five is a 3¼-in. dia. work roll, and in contact with this on each side at 45° from the vertical is an intermediate roll 6¼ in. in dia., each of which is backed by a 17¾-in. dia. roll. The work and backing rolls below the strip are 8¼ and 19⅜ in. in dia. respectively. The lower work roll and the two upper intermediate rolls are driven by a 600-h.p. motor. The mill is designed to roll strip up to 17 in. wide at delivery speeds of 600–1200 ft./min. —R. A. R.

MACHINERY FOR IRON AND STEEL PLANT

The Competition between Gas and Steam Turbines. F. Münzinger. (Stahl und Eisen, 1948, vol. 68, Mar. 25, pp. 114–120). This discussion of the relative merits of gas and steam turbines indicates that the heat consumption of a steam-turbine power station can be reduced by at least 10% by raising the initial and intermediate steam temperatures to 600° C. The comparison between gas and air turbines shows that for open-circuit gas turbines solid fuel must be gasified. Air turbines are much more economical than open-circuit gas turbines unless it is possible to clean the hot producer gas for the latter very cheaply and efficiently. The steam turbine will most probably remain supreme in large power stations for a long time to come. Gas and air turbines are most suitable for 200 to 15,000-kW. units. In deciding what type of gas producer to use for gas turbines it is necessary first to ascertain whether tar is to be recovered or not.—R. A. R.

Maintenance Methods Symposium—Steam Turbine Inspection and Maintenance. H. A. Smith. (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 89–91). A brief account is given of experience in the maintenance of several types of steam turbine at the works of the Carnegie-Illinois Steel Corporation.—R. A. R.

Report of Activities of AISE Standardization Committee —1947. F. W. Cramer. (Iron and Steel Engineer, 1948, vol. 25, Feb., pp. 60–62). An outline is given of the activities of the Standardization Committee of the Association of Iron and Steel Engineers during 1947, and the various research programmes at present in progress are enumerated. The recognized wire sizes for mill-type motors as outlined in the National Electric Code sponsored by the National Board of Fire Underwriters are tabulated ; this code, which has been accepted by the American Standards Association, is regarded as the standard for electric wiring and apparatus and will be studied by the Committee during the coming year. The following reports of Sub-Committee activities, together with descriptions and tabulations of the respective standards (standards Nos. 2, 3, and 4) are appended. —J. R.

Report of Committee on Standardization of Dimensions of Enclosed Switches. E. L. Anderson and A. N. Reynolds, jun. (*Ibid.*, p. 62).

Report of Committee on Standardization for Machined Surface Finishes. H. B. Conover. (*Ibid.*, pp. 62–63).

Report of Committee on Sling and Crane Chain Standards. J. B. Mitchell and J. F. Byers. (*Ibid.*, p. 63).

A.I.S.E. Standard No. 2—Standard Dimensions for Enclosed Switches. (*Ibid.*, p. 64).

A.I.S.E. Standard No. 3—Standards for Machined Surface Finishes. (*Ibid.*, p. 65).

A.I.S.E. Standard No. 4—Sling and Crane Chain Standards. (*Ibid.*, pp. 66–68).

A.I.S.E. Standard No. 5—Standards for Wiring Diagrams. (*Ibid.*, pp. 69–70). The requirements of Standard No. 5 of the Association of Iron and Steel Engineers are described. This standard applies to diagrams for all controls designed especially for steelworks service, including main and auxiliary mill drives, processing lines, cranes, etc., but excluding catalogue controllers (such as line starters). The standard was developed by a joint committee of the Association of Iron and Steel Engineers and the N.E.M.A., and is under consideration by the Codes and Standard Committee of the latter organization. —J. R.

Proposed New AISE Crane Specifications. I. E. Madsen. (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 73–79). The new specifications proposed by the Association of Iron and Steel Engineers for crane gears are discussed.

Motor Selection for EOT Cranes. M. A. de Ferranti. (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 80–88). A method of selecting motors for electric overhead travelling cranes, which was submitted to a committee of the Association of Iron and Steel Engineers for adoption as a standard, is explained.—R. A. R.

Crane Cab Cooling at High Operating Temperatures. (Steel, 1948, vol. 122, Mar. 22, p. 82). Equipment for cooling the cabs of melting-shop and casting-pit cranes is described. A steel shield is fixed so as to provide a 6-in. air gap below the cab floor, and the roof, walls, and floor of the cab are provided with fibre-glass insulation.—R. A. R.

Electric Counterweights for Ingot Stripping Cranes. R. J. Harry. (Iron and Steel Engineer, 1947, vol. 24, Mar., pp. 105–107). A description is given of a modification to the usual circuit controlling a stripper crane, by means of which the hoist motor acts as an electric counterweight. It is claimed that the dropping of the ingot when " stickers " are encountered is thus effectively prevented.—J. R.

Maintenance Methods Symposium—Maintenance of Main Drive Motors and Motor-Generator Sets. V. E. Schlossberg. (Iron and Steel Engineer, 1948, vol. 25, Mar., pp. 96–98). The system of maintenance for mill motors and electrical equipment at works of the Inland Steel Company is described.—R. A. R.

Electronic and Servo Electronic Controls and Their Application to the Iron and Steel Industry. W. G. Thompson. (Journal of The Iron and Steel Institute, 1948, vol. 158, Apr., pp. 497–509).

Electric Control Gear for Steel-Mill Auxiliaries. R. A. West. (Journal of The Iron and Steel Institute, 1948, vol. 158, Mar., pp. 357–375).

Automatic Regulators for Electric Furnace Electrodes. L. Peytavin. (Journal du Four Electrique, 1947, vol. 56, Apr.–May, pp. 27–29). The principles of electrode regulators are discussed.—R. F. F.

Mechanical Equipment for Electric Furnaces in American Steelworks. R. Boutigny. (Journal du Four Electrique, 1947, vol. 56, June–July, pp. 42–46). This is a summarized extract of a conference at the Centre d'Études Supérieures de la Métallurgie on April 22, 1947. The equipment described relates to arc furnaces of 10–100 tons, and includes the more common types for rapid charging, tilting, and electrode control.—R. F. F.

WELDING AND FLAME-CUTTING

The Dissociation of Nitrogen in the Welding Arc. J. D. Fast. (Philips Research Reports, 1947, vol. 2, Oct., pp. 382–398). For temperatures in the range from 5000–10,000° K. the dissociation of nitrogen is computed on the basis of spectroscopic data, and for three different values of the dissociation energy, *viz.*, 7·383, 8·573, and 9·764 electron volts ; in view of a

recent investigation by Gaydon and Penney the highest value is probably the correct one. At 10,000° K., and a pressure of 1 atm. the degree of dissociation is 99% at least; at 5000° K. 25·1% of the nitrogen will be dissociated if the dissociation energy amounts to 7·383 eV., but only 1·63% will be dissociated if the dissociation energy is 9·764 eV. Two cruder methods of computation give results that differ only slightly from these "exact" values.—R. A. R.

How to Use Arc Welding Electrodes. H. W. Westendarp, jun. (Steel Processing, 1948, vol. 34, Jan. pp. 20–22, 44). The technique for arc welding, with special reference to current strength, length of arc, angle of electrode, and speed of travel, is described with illustrated examples of the effects of variations in these factors.—R. A. R.

Arc Welding for Mechanical Construction. L. Tamisey. (Machines et Métaux, 1948, vol. 32, Apr., p. 142). The applications of arc welding to machine construction are discussed.—R. F. F.

Welding in the U.S.A. F. Faltus. (Svařování, 1948, vol. 8, No. 2, pp. 17–26). [In Czech]. This is a review of welding methods and equipment in the United States.—R. A. R.

Welding Offers New Aid. C. W. Brett. (British Steelmaker, 1948, vol. 14, Mar., pp. 140–142). Examples of welds to heavy machinery are cited. These include the repair of the frame of a rolling-mill stand, repairing the centre column of a furnace-charging machine, and a marine engine crankshaft.—R. A. R.

Welds on Cast Iron. H. Seymour. (Mining Magazine, 1948, vol. 78, Mar., pp. 142–143). Techniques are described for the finishing of welds on cast iron.—R. A. R.

Effect of Welding on Austenitic Manganese Steel. F. E. Benson and H. S. Avery. (Canadian Machinery, 1947, vol. 58, July, pp. 124, 126, 127).

Producing Diesel Engine Turbosuperchargers. F. R. Ericson. (Iron Age, 1948, vol. 161, Mar. 25, pp. 72–77). The procedures are described for flash welding Diesel engine supercharger discs on to shafts, machining the supercharger blades from blanks, and atomic-hydrogen welding the blades to the disc.—R. A. R.

Welding of Nickel Alloys. A. E. Williams. (Engineering and Boiler House Review, 1948, vol. 63, Mar., pp. 77–79). Techniques are described for the oxy-acetylene and arc welding of nickel, Monel, and Inconel. The preparation of the edges and an oxy-acetylene method of welding nickel-clad steel plate is also given.—R. A. R.

Argon Arc Welding. W. Gerritsen. (Revue de la Soudure/Laschtijdschrift, 1948, vol. 4, No. 1, pp. 3–16). The principles and technique of argon arc welding are briefly discussed. The equipment and technique are described and welding data given for various metals including stainless and special steels.—R. F. F.

Mechanized Inert-Gas-Shielded Arc Welding. H. T. Herbst. (Welding Journal, 1948, vol. 27, Feb., pp. 111–117). Descriptions are given of the equipment and procedure for welding stainless steel, silicon steel, and non-ferrous metals, with and without welding rods in an inert atmosphere such as argon or helium, using a machine to move the torch along the work.—R. A. R.

Arc Welding of Stainless Steels. J. Laurens. (Machines et Métaux, 1948, vol. 32, Mar., pp. 85–88). The properties of nickel–chromium and chromium stainless steels are briefly discussed with special reference to those affecting welding technique. The welding procedure to be adopted for each kind of steel is described.—R. F. F.

Stainless Steel Lining of Vessels. (Welder, 1948, vol. 17, Jan.–Mar., pp. 20–21). The procedure by which a stainless steel lining was electrically welded to a large steel rectifying column is described.—R. A. R.

Electric Welding of Rustless Steel. R. Popišil. (Svařování, 1948, vol. 8, No. 1, pp. 1–3). [In Czech]. The electric welding of three stainless steels, namely, the pearlitic 12–16% chromium, the ferritic 16–26% chromium, and the austenitic 18/9 chromium–nickel types, is described.—R. A. R.

Standard Rules for Field Welding of Steel Storage Tanks. (American Welding Society, 1947, Pamphlet D5.1-47).

Hardfacing with the Metallic Arc. A. Markin. (Australian Welding Institute: Australasian Engineer, 1948, Jan. 7, pp. 50–57). A comprehensive account is given of the electrodes and procedures for depositing layers of abrasion-resisting alloys by welding on to parts subject to heavy wear. The effects of various forms of preheating and postheating on the microstructure and properties of steel are indicated, and a nomograph is presented for rapidly determining the temperature range of martensite formation of steel of almost any composition.—R. A. R.

Hard-Facing. A. Vamberský. (Svařování, 1948, vol. 8, No. 1, pp. 7–11). [In Czech]. Methods of depositing a layer of a hard alloy on the surface of steel with the oxy-acetylene torch and by electric welding are described. In some methods the electrode has a mild steel core with the alloying elements in the flux coating, and in others a steel tube is filled with a hard-metal core. Another method is to spread the hard metal on the surface in powder form, and to melt it with a torch.—R. A. R.

Some Metallurgical Aspects of Carbon Steel Spot Welding. J. Heuschkel. (Steel, 1948, vol. 122, Mar. 15, pp. 93–95, 124, 126, 128; Mar. 22, pp. 67–69, 104–109). *See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 402.

Submerged Melt Welding of Hardenable Steels. E. A. Clapp and E. L. Frost. (Steel Processing, 1948, vol. 34, Feb., pp. 80–83). *See* Journ. I. and S.I., 1948, vol. 159, May, p. 95.

German Research and Development in Tank Armour Welding. (Combined Intelligence Objectives Sub-Committee, 1948, Report No. XXXIII-10: H.M. Stationery Office.)

Synthesis of Metal Welding Flux. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1678: H.M. Stationery Office).

The Stress-Relieving of Welded Steam Boiler Drums. W. J. Kaufman. (Lastechniek, 1948, vol. 4, Feb., pp. 13–18; Mar., pp. 26–31). [In Dutch]. The relief of welding stresses, the tempering of the hardened zone, and the prevention of ageing in welded boiler drums by annealing and peening are discussed.—R. A. R.

Induction Heating for Preheating and Normalizing Welds. (Energie, 1948, vol. 32, Apr., p. 88). The Smith-Dolan method of induction heating and its application to preheating chromium–molybdenum or molybdenum steel tubes before welding are briefly described.—R. F. F.

Induction Brazing. G. Gourod. (Machine Moderne, 1947, vol. 41, May, pp. 8–16).

A Brief Review of Brazing Processes. H. R. Brooker. (Sheet and Strip Metal Users' Technical Association: Sheet Metal Industries, 1947, vol. 24, Oct., pp. 2041–2045; Nov., pp. 2253–2256; Dec., pp. 2457–2462). The paper describes the established practices and materials which are now available to the engineer who seeks to use brazing as an assembly method.—R. A. R.

Notes on Oxygen Cutting. C. G. Bainbridge. (Iron and Coal Trades Review, 1948, vol. 156, Apr. 2, pp. 689–691). These notes supplement the information in the author's earlier paper (*see* Journ. I. and S.I., 1948, vol. 159, May, p. 96). Information is given on the

influence of plate-edge preparation by oxy-acetylene cutting on subsequent welding ; cutting stainless steel and thick sections ; cutting with a heavy-duty blowpipe in a machine ; and cutting with a tubular flux-coated electrode through which oxygen is supplied.—R. A. R.

The Uses of Flux-Injection Cutting for Stainless Steels. G. E. Bellow. (Welding Journal, 1948, vol. 27, Feb., pp. 118–124). *See* Journ. I. and S.I., 1948, vol. 158, Feb., p. 273.

Cutting Stainless Steel and Other Oxidation-Resistant Alloys. R. Priess. (Southern Power and Industry, 1948, vol. 66, No. 1, pp. 62–64 : Chemical Abstracts, 1948, vol. 42, Mar. 10, p. 1543). Three new processes have been developed for flame-cutting the oxidation-resistant alloys, heretofore, a slow, difficult process. The Linde Air process uses a non-hygroscopic, non-toxic, finely divided, iron-rich powder which is fed into the oxygen stream from the outside of the preheat flame. The powder burns in the oxygen flame and creates a high temperature reaction. The products of combustion provide the necessary fluxing action. Powder flows are $\frac{1}{4}$ to $\frac{1}{2}$ lb./min., and cutting speeds are comparable to those of carbon steel. Special attachments and a powder dispenser are added to conventional oxy-acetylene equipment. The Air Reduction process is quite similar ; it employs an oxide-eliminating powdered flux which is carried by the cutting oxygen through the tip to the point of cut. The Arcos Corporation high-temperature reaction is obtained by the use of an electric arc and a stream of oxygen. Necessary equipment consists of a tubular mild-steel coated rod, special holder, oxygen supply, and either an A.C. or D.C. welder. These rapid cutting methods have little practical effect on corrosion resistance, owing to later operations.

MACHINING AND MACHINABILITY

The Maintenance of Electrical Machinery in Iron and Steel Works. G. S. Martin and M. Y. Harvey. (Journal of The Iron and Steel Institute, 1948, vol. 158, Apr., pp. 510–520).

A Further Report on the German Bolt and Nut Industry. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1452 : H.M. Stationery Office).

Air Contamination during Machining of Beryllium Stainless Steel. A. C. Titus. (Journal of Hygiene and Toxicology, 1948, vol. 30, Jan., pp. 29–31).

Finish-Machining with Diamond Tools. P. Grodzinski. (Werkstatt und Betrieb, 1948, vol. 81, Feb., pp. 33–34). Brief notes on modern methods of finish-grinding and polishing and the surface flatness which can be achieved with diamond tools are presented.—R. A. R.

Piercing and Cutting Hard Materials. L. Guimin. (Machines et Métaux, 1948, vol. 32, Feb., pp. 61–62). The application of electrolytic technique to cutting or piercing hard materials such as high-speed steels or carbides is reviewed.—R. F. F.

Contour Sawing Hardened Steels and Carbides. (Iron Age, 1948, vol. 161, Feb. 26, p. 73). A brief description is given of a diamond band saw for cutting tungsten carbides and hardened steel. For cutting materials up to 2 in. thick the band has two diamond-impregnated segments per inch. Pieces of tungsten carbide up to 2 in. thick have been cut at the rate of 0·05 sq. in./min. —R. A. R.

The Technical Standardization of Machine Shop Practice. G. I. Shandrenko. (Stal, 1948, No. 1, pp. 68–71). [In Russian]. This is a discussion of the organization to be adopted in machine shops for the greatest efficiency.—S. K.

CLEANING AND PICKLING

The Cleaning of Metals. Part I—Choice of Process and Cleaning Agent. Part II—Alkaline Cleaners. Part III—Further Operations. Part IV—Emulsifiable Cleaners. Part V—Mechanical Cleaning Machines. R. Groves. (Metallurgia, 1947, vol. 37, Nov., pp. 40–42 ; Dec., pp. 100–102 ; 1938, Jan., pp. 147–149 ; Feb., pp. 217–219 ; Mar., pp. 267–268).

Obtaining Clean Metal Surfaces by Mechanical Abrasion in a Vacuum, and Studying these Surfaces by Electronic Diffraction. R. Courtel. (Comptes Rendus, 1948, vol. 226, Mar. 8, pp. 793–795). In order to determine the part played by air and impurities in the atmosphere during surface-finishing processes, grinding tests on a piece of ordinary steel were carried out *in vacuo* in an electronic analyser and the surfaces obtained were examined by electron diffraction. The motor driving the grinding machine was also enclosed in the vacuum and precautions were taken to avoid deflection of the electrons by its magnetic field. The results of the examinations are outlined and discussed. The operation was repeated in air and the results observed are compared with those obtained *in vacuo*.—J. C. R.

Degreasing of Metallic Parts. (Galvano, 1947, vol. 16, June, pp. 8–9). The various methods of degreasing metals are discussed with special reference to the use of trichlorethylene.—R. F. F.

Degreasing of Metallic Parts. P. Courtine. (Galvano, 1947, vol. 16, July, p. 7). Degreasing of metals using an alkaline solution under pressure is discussed.—R. F. F.

Reclaiming Solvent Cleaners. J. Albin. (Iron Age, 1948, vol. 161, Feb. 12, pp. 74–75). A brief description is given of a small distillation unit for reclaiming used petroleum solvent cleaning solutions.—R. A. R.

Pickling of Plain Carbon and Low Alloy Steels. M. Smialowski. (Hutnik, 1947, vol. 14, Jan., pp. 2–9). [In Polish]. The paper discusses acid-pickling and other methods of surface cleaning. The author considers the influence of the chemical composition and structure of the steel under treatment and describes the properties of different types of scale formed at various temperatures. From diffusion experiments he concludes that hydrogen diffuses more readily through an annealed sheet than through cold-rolled material.—W. J. W.

The Sodium Hydride Process and New Method of Descaling Metals. N. L. Evans. (Wire Industry, 1948, vol. 15, Feb., pp. 105–107). The sodium hydride descaling process has already been described (*see* Journ. I and S.I., 1946, No. II, p. 75A). In this paper the equipment for applying it to the cleaning of wire and strip is described in detail.—R. A. R.

Salt Descaling Baths. H. Drever. (Industrial Heating 1948, vol. 15, Jan., pp. 40–52, 166–168). The Du Pont and the "Virgo" processes of descaling in sodium hydride baths are described with details of the equipment used. The two processes are distinguished mainly by the difference in the bath temperatures which are 700° and 900° F. respectively.—R. A. R.

Sodium Hydride Pickling. A. Normand. (Métallurgie, 1948, vol. 80, Mar., p. 25). An account is given of the sodium hydride pickling process and the plant used is described. The advantages claimed over acid pickling processes are outlined.—J. C. R.

Flame Cleaning. G. W. Rigby. (Coke and Gas, 1948, vol. 10, Mar., pp. 89–95). The equipment and procedures for removing scale and corrosion products from steel in preparation for painting are described.—R. A. R.

Preparing Surfaces for Metallizing. R. Mansell. (Steel, 1948, vol. 122, Mar. 1, pp. 93–95, 119–125).

The methods adopted to clean and roughen surfaces which are to be metal-sprayed are described.—R. A. R.

New Techniques in Conditioning Stainless Steel. A. E. Hamilton, jun. (Iron and Steel Engineer, 1948. vol. 25, Feb., pp. 78–87). Descriptions are given of design features and purposes of (1) the "slab grinder," a new machine for the automatic wet-conditioning of blooms, billets, slabs, plates, and sheet bar, and (2) the equipment used in new machine techniques for wet-grinding, and polishing of cold-rolled strip and sheet. Although the descriptions are given with particular reference to use on straight chromium and 18/8 stainless steels, the methods are also applicable to the conditioning of precious metals, alloys, plastics, non-ferrous metals, etc.—J. R.

Necessity for Good Polishing. J. Liger. (Galvano, 1947, vol. 16, June, pp.7–8). The need for good polishing to prevent rusting after plating is discussed. As an example, a simple test, in which six sheets are polished to different degrees before nickel plating, is described. The more polished specimens will be the last to be affected by rust.—R. F. F.

Metal Polishing. E. J. Wright. (Plating, 1948, vol. 35, Jan., pp. 35–37, 98). The author suggests methods of improving the metal-polishing industry in Australia, confining his remarks to the materials used.—R. A. R.

Electropolishing—A Survey. S. Wein. (Metal Finishing, 1948, vol. 46, Feb., pp. 71–77). The literature and patents relating to electrolytic polishing are surveyed. There are 57 references.—R. A. R.

Electropolishing. J. J. Dale. (Australian Institute of Metals: Australasian Engineer, 1948, Jan. 7, pp. 65–71). A comprehensive account is given of the application of electrolytic polishing for metallographic and industrial purposes. Solutions and processes for polishing stainless steel, carbon steel, and several non-ferrous metals are described.—R. A. R.

Rapid Electropolish and Etch. A. De Sy and H. Haemers. (Metal Progress, 1948, vol. 53, Mar., pp. 368–371). The preparation of the electrolyte from perchloric acid and ethyl alcohol for electrolytic polishing is described. Examples of the structure obtained in carbon and alloy steels are shown by micrographs, and an explanation is given of the fact that many pits appear in very low carbon steels deoxidized with aluminium. It is pointed out that there is very little danger of explosion when using the standard electrolyte described.—R. A. R.

PROTECTIVE COATINGS

Coatings Research. (Iron and Steel, 1948, vol. 21, Mar., pp. 87–90). **The South Wales Laboratories at Sketty Hall.** (Metallurgia, 1948, vol. 37, Mar., pp. 259–263). **Steel Research Laboratories in South Wales.** (Engineer, 1948, vol. 185, Feb. 20, pp. 179–181). A description is given of the research laboratories of the British Iron and Steel Research Association at Sketty Hall, Swansea. The main work is closely concerned with the coating problems associated with the South Wales tinplate industry, but there is an important section engaged on steelmaking problems.—R. A. R.

The Structure of Metallic Surfaces. J. Liger. (Galvano, 1947, vol. 16, May, pp. 7–9). The structure of metals is discussed with special reference to the preparation of metals for plating.—R. F. F.

Industrial Electrodeposition. R. E. Wilson. (Metal Industry, 1948, vol. 72, Mar. 12, pp. 211–213; Mar. 26, pp. 251–254). The qualities of adhesion of electrodeposited coatings are discussed. The effect of heating chromium and nickel coatings at elevated temperatures was investigated, and the results are plotted graphically. Corrosion-fatigue tests results are also presented. The value of chromium deposition on bearing surfaces is pointed out, accompanied by illustrations. The repair of worn bearing surfaces by nickel deposition permits the salvage of components which are expensive to replace. —R. L. B.

A New Method for Magnetic Measurement of the Thickness of Composite Copper and Nickel Coatings on Steel. A. Brenner and E. Kellogg. (Plating, 1948, vol. 35, Mar., pp. 243–246). A detailed description is given of the "Magne-gage" for determining the thickness of non-magnetic coatings and magnetic coatings on steel. The instrument measures the attractive force between the specimen and two permanent magnets of different strengths. The relative thicknesses of the copper and nickel layers of a composite coating can be measured by utilizing the difference in curvature of the calibration curves of the two magnets. Some results with it are presented and the accuracy of the method is discussed. —R. A. R.

Thickness Testing of Paint and Metal Coatings on Steel. D. H. Lee. (Sheet Metal Industries, 1948, vol. 25, Mar., p. 555). A development of the Spencer-Timms magnetic thickness tester for non-magnetic coatings on steel is described. In this the magnetic attraction is determined by a mechanical balance consisting of a beam 7½ in. long with a sliding weight.—R. A. R.

Selection of Protective Coatings. K. G. Compton, (Canadian Chemistry and Process Industries, 1947. vol. 31, Nov., pp. 1027–1030, 1033). The electrochemical theory of corrosion is discussed and various types of protective coatings, their selection and testing, are dealt with.

The Protection and Finish of Pressed Steel Kitchen Equipment. W. F. Coxon. (Sheet Metal Industries, 1948, vol. 25, Jan., pp. 122–124). The following processes for preventing the corrosion of steel kitchen equipment are described: (1) Surface cleaning; (2) passivation; (3) glazing of seams and crevices; and (4) applying a priming coat and two finishing coats.—R. A. R.

Selection of Protective Coatings. K. G. Compton. (Canadian Chemistry and Process Industries, 1947, vol. 32, pp. 1027–1030, 1033: Chemical Abstracts, 1948, vol. 42, Feb. 10, p. 855). A discussion of the selection of protective coatings for metals. Electrochemical theory of corrosion, types of coatings, and the final selection of the coatings are considered. Several types of testing appliances are illustrated.

Proceedings of the 34th Annual Convention of the American Electroplaters' Society. (American Electroplaters' Society, June, 1947). The 34th Annual Convention of the Society was held at Detroit on June 23–27, 1947. Abstracts of the papers of ferrous interest follow. —R. A. R.

The Physical Properties of Electrodeposits. A. Brenner and C. W. Jennings. (*Ibid.*, pp. 25–31). This is a report on Research Project No. 9 which was restricted to tests on the physical properties of nickel deposits to obtain data to extend the engineering applications. Information on the strength, electrical and magnetic properties is given.—R. A. R.

Physical Properties of Electrodeposited Chromium. A. Brenner, P. Burkhead, and C. Jennings. (*Ibid.*, pp. 32–73: Journal of Research of the National Bureau of Standards, 1948, vol. 40, Jan., pp. 31–59). The following properties of chromium, deposited under a wide variety of plating conditions, have been measured: Density, hardness, tensile strength, Young's modulus of elasticity, ductility, electrical

resistivity, and stress in the deposit. The oxygen and hydrogen content were determined. The effect of heat-treatments up to 1200° C. on certain of these properties was studied and some work has been done on the properties of chromium–iron alloys deposited from modified chromic acid solutions. A relation between the hydrogen and oxygen content of the deposits has been shown to exist, and the effect of the oxygen content on the physical properties has been studied.

Stress in Electrodeposits—Its Significance. K. G. Soderberg and A. K. Graham. (*Ibid.*, pp. 74–96). The literature on stress in electrodeposited coatings is reviewed and an investigation of the stresses in nickel deposits 0·0001 and 0·001 in. thick on annealed copper and spring steel strips 3 × 0·5 in. is described. Data are presented showing the effect of changing the plating conditions on the stress. The method of calculating the stress from the curvature of the initially flat strip is explained in an appendix.—R. A. R.

Stress in Electrodeposit Nickel. W. M. Phillips and F. L. Clifton. (*Ibid.*, pp. 97–114). Data are presented which show the effects of plating conditions in a Watts nickel bath on the stress in the deposited nickel. The single nickel salt, nickel chloride, and boric acid, together produce a tensile stress of about 14,000 lb./sq. in. The stress increases with rising *p*H value. Raising the bath temperature reduces the stress. Agitation, and changes in current density have no appreciable effect on the stress. Contamination by iron considerably increases the tensile stress. When a composite coating of copper, nickel, and chromium fails as a result of tensile stress, most of the stress is in the nickel.—R. A. R.

Protective Power and Porosity of Electrodeposits. N. Thon. (*Ibid.*, pp. 128–134). Theories on the causes and types of porosity in electrodeposited coatings are put forward and porosity tests are critically discussed. The well known ferroxyl test using a ferricyanide reagent to determine porosity was found to be of doubful value in some cases as the conventional reagents attack nickel and cause perforations in it. A mild reagent high in ferricyanide and very low in sodium chloride is recommended, but even this has a limited value as it indicates only gross defects likely to result in rapid corrosion of the base metal.—R. A. R.

Evaluation of Methods for Determining the Thickness of Electrodeposited Coatings. H. J. Read. (*Ibid.*, pp. 135–145). The merits and limitations of microscopical, magnetic, and chemical methods of determining the thickness of electrodeposited coatings are compared.—R. A. R.

Deposition of Nickel and Cobalt by Chemical Reduction. A. Brenner and Grace Riddell. (*Ibid.*, pp. 156–170). A process for depositing nickel from an ammoniacal solution containing hypophosphite has been described (*see* Journ. I. and S.I., 1946, No. II, p. 118A). In the present paper the authors describe in detail an extension of this method to include deposition of nickel from acid solutions, and of cobalt and cobalt–nickel alloys from ammoniacal solutions.—R. A. R.

Recent Developments in the Use of Conversion Coatings on Zinc. J. E. Stareck and W. S. Cibulskis. (*Ibid.*, pp. 171–179). The corrosion resistance coatings on steel can be increased by treating the coating anodically or chemically to convert part of the zinc to the oxide or chromate or a combination of the two. Data from outdoor exposure tests and salt-spray tests on these "conversion coatings" are presented and the corrosion resistance is related to the coating thickness, presence of impurities, and the process used.—R. A R.

Barrell Chromium Plating. G. Dubpernell and S. M. Martin. *Ibid.*, pp. 180–200). A brief review is given of previous attempts to plate small parts with chromium by tumbling in a barrel. Present successful methods and equipment are described. A horizontal rotating steel cylinder with an inside anode is used. The inside of the cylinder and the parts are plated simultaneously.—R. A. R.

Bulk Nickel Plating. H. Strow. (*Ibid.*, pp. 201–207). The technique for nickel-plating parts in horizontal rotating cylinders is described with special reference to the use of high sulphate and high chloride solutions.—R. A. R.

Some Effects of Copper in Nickel Plating Solutions. D. T. Ewing and W. D. Gordon. (*Ibid.*, pp. 213–217). Data are presented on the effects produced on the appearance, adhesion, and ductility of nickel coatings by the addition of small amounts of copper to three types of plating solution, namely, a *p*H-5·2 Watts solution, a *p*H-2·2 Watts solution, and a nickel–cobalt bath at *p*H 3·75. With these three solutions loss in ductility was noted when the copper additions exceeded 25, 50, and 25–50 mg./litre respectively.—R. A. R.

Extraction Methods Applied to the Analysis of Electroplating Baths—Determination of Zinc and Other Impurities in Nickel Plating Solutions. E. J. Serfass and W. S. Levine. (*Ibid.*, pp. 218–227).

Modern Application of Electroplating Solution Purification. B. C. Case. (*Ibid.*, pp. 228–248). Copper, zinc, lead, and iron in any combination can be removed from nickel plating solutions by electrolytic means; batch and continuous methods are outlined which can be applied to practically every nickel solution used. Electrolytic purification need not be limited to nickel solutions. Continuous carbon treatment for removing organic impurities cannot be used as generally as the electrolytic method of removing metallic contamination.—R. A. R.

The Disposal of Plating Room Wastes. B. F. Dodge and D. C. Reams. (*Ibid.*, pp. 249–269). This paper reviews the present position of the problem of disposing of waste liquors from plating plants. Various methods of treating wastes, particularly chemical methods are discussed. There are 27 references to recent literature.—R. A. R.

Electroless Plating on Metals by Chemical Reduction. (Steel Processing, 1947, vol. 33, Nov., pp. 677–678, 687). A brief description is given of a process, developed by A. Brenner and G. E. Riddell, for plating nickel or cobalt on metal surfaces without applying an electric current. A nickel or cobalt salt is chemically reduced by hypophosphite solution at above 90° C. A catalyst such as steel or nickel must be present to initiate the reaction.—R. A. R.

Smoothing Action As a Mechanism in Bright Nickel Plating. G. E. Gardam. (Journal of the Electrodepositors' Technical Society, 1947, vol. 22, pp. 155–168). Electrodeposits of nickel from solutions containing zinc, cadmium or iron, made on a serrated cathode, have been shown by microscopical examination of the cross section, to be thicker in the hollows than on the crests. Nickel plating solutions which yield bright deposits have been demonstrated, by reflectivity tests of deposits made on slightly matt surfaces, to show a similar smoothing action, but on a smaller scale. The theoretical and practical importance of this action is discussed.

Chromium Plating of Cutting Tools. H. I. Feldstein, S. N. Korbmann, and F. Ya. Polniakova. (Stanki i Instrumenty, 1947, Apr., pp. 24–26 : [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Jan., p. 7). The preparation of surfaces by electrolytic polishing, the chromium-plating processes, and results of tests on chromium-plated tools are discussed.—J. C. R.

Plating Chromium by Thermal Decomposition of Chromium Hexacarbonyl. B. B. Owen and R. T. Webber. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2306 : Metals Technology, 1948, vol. 15, Jan.). Coatings of chromium were deposited on 36 1-in. discs of steel by the thermal decomposition of chromium carbonyl in the presence of hydrogen. The plating rate was varied between 0·001 and 0·002 in./hr. Plating at 450° and 625° C. gave a very good bond, and the coatings were extremely hard (2000 Vickers).—R. A. R.

Porous Chrome Hardening of Diesel Engine Cylinders. C. D. B. Williams. (Diesel Engine Users' Association : Engineering, 1948, vol. 165, Feb. 6, p. 139 : Mechanical World, 1948, vol. 123, Jan. 30, pp. 118–120). The Van der Horst method of producing porous chromium plating on Diesel-engine cylinder walls is described, and its advantages in greatly increasing the life of the cylinder are discussed.—R. A. R.

The Effect of Plating Conditions on the Structure of Thick Chromium Electrodeposits. J. J. Dale. (Electrodepositors' Technical Society, Third International Conference on Electrodeposition : Sheet Metal Industries, 1948, vol. 25, Mar., pp. 531–539, 546). The paper describes (*a*) investigations of the microstructure of electrodeposited chromium, its relation to plating conditions, and its connection with the channel network produced by surface etching of deposits ; (*b*) a few experiments on the effect of heating on the microstructure of the electrodeposits, and some attempts to identify the minor constituent in the structure by analytical methods. The following changes in plating conditions cause refinement of the channel network : (1) Lowering the bath temperature ; (2) decreasing the sulphate ratio ; and (3) at temperatures above 55° C., increasing the current density ; below 55° C., decreasing the current density. These conclusions substantially confirm the work of Cymboliste.—R. A. R.

Notes on Nickel and Chromium Plating. C. F. Nixon and R. C. Olsen. (Plating, 1948, vol. 35, Jan., pp. 27–33, 95). Experience at a plating plant of the General Motors Corporation in depositing chromium over bright nickel plate in the same plating machine is described. Several types of plating rack are illustrated and the causes of rough and stained coatings are examined.—R. A. R.

Physical Properties of Electrodeposited Metals. 1. Nickel. (Plating, 1948, vol. 35, Jan., pp. 52–56). The literature on the properties of electrodeposited nickel coatings is surveyed in connection with Research Project No. 9 of the American Electroplaters' Society. An extensive bibliography is appended. (*See* "The Physical Properties of Electrodeposits" by A. Brenner and C. W. Jennings, abstract on p. 223).

Nickel Coatings and Nickel Baths. J. Salauze. (Galvano, 1947, vol. 16, July, pp. 9–16). Details are given of nickel-plating baths proposed by various investigators.—R. F. F.

Hot Dip Galvanizing—What It Is—And How It's Done. R. Mansell. (Canadian Metals and Metallurgical Industries, 1947, vol. 10, Dec., pp. 20–21). The hot-dip galvanizing process is described. The nature of the intermediate iron–zinc alloy layers and factors causing embrittlement of the outer layers are explained.—R. A. R.

Galvanising Sheet and Strip Steel. H. Edwards. (Swansea and District Metallurgical Society : Iron and Coal Trades Review, 1948, vol. 156, Feb. 6, pp. 265–269). Equipment and methods used in the hot-dip galvanizing of sheet and strip steel are described, and reference is made to various processes which have been developed with the object of improving the product. Special attention is given to the Sendzimir process.—J. R.

Applications of Zinc Coatings by Hot Dipping. R. Steele. (Metal Finishing, 1947, vol. 45, Dec., pp. 71–76). A comprehensive account is given of the hot-dip galvanizing process.—R. A. R.

Alloy Additions to Hot-Galvanizing Baths. H. Bablik and F. Götzl. (Iron and Steel Institute, 1948, Translation Series, No. 342). This is an English translation of a paper which appeared in Korrosion and Metallschutz, 1941, vol. 17, Apr., pp. 128–130. (*See* Journ. I. and S.I., 1942, No. II, p. 181A).

The Lead-Zinc Galvanizing Process. H. Bablik and F. Götzl. (Iron and Steel Institute, 1948, Translation Series, No. 339). This is an English translation of a paper which appeared in Metallwirtschaft, 1942, vol. 21, Nov. 27, pp. 718–720. The advantages and disadvantages are pointed out of a process of galvanizing in which the bath consists of a layer of zinc on top of molten lead.—R. A. R.

The Formation of Hard-Zinc in the Lead-Zinc Galvanizing Process. H. Bablik. (Iron and Steel Institute, 1948, Translation Series, No. 339). This is an English translation of a paper which appeared in Stahl und Eisen, 1944, vol. 64, Feb. 24, pp. 120–122. (*See* Journ. I. and S.I., 1945, No. I, p. 26A).—R. A. R.

Zinc Coatings from Cyanide Baths. J. Salauze. (Galvano, 1948, vol. 17, Feb., pp. 7–13). Literature on the technique of electrogalvanizing in cyanide baths is reviewed and operating details are given.—R. F. F.

Setting Up a Hot Galvanizing Shop. A. Gordet. (Galvano, 1947, vol. 16, Feb., pp. 18–19). General principles for setting up hot-galvanizing shops are discussed.—R. F. F.

The "Deoxidation" Process of Hot Galvanizing. A. Gordet. (Galvano, 1947, vol. 16, May, pp. 17–19 ; July, pp. 17–19, Nov., pp. 15–16). The "deoxidation" process of hot galvanizing is critically discussed.—R. F. F.

The Hot-Dip Tinning of Steel Spoons and Forks. K. W. Caulfield and W. E. Hoare. (Tin and Its Uses, 1948, No. 19, Mar., pp. 8–11). An investigation is described of the best method for tinning mild steel spoons and forks intended for export to poorly developed overseas countries and for use in canteens and hostels and by railway companies and the Services. The recommended procedure comprises : (*a*) Initial preparation of the blanks of cold reduced and cold formed mild steel, by rumbling and vapour-degreasing ; (*b*) pickling in, successively, hydrochloric, nitric, and again hydrochloric acids, with intermediate water rinsings ; (*c*) fluxing in an aqueous flux of $ZnCl_2$, 24% by weight, NH_4Cl 3%, NaCl 6% containing 0·5% HCl by volume ; (*d*) rough tinning at 285° C. in pure tin under a flux of four parts $ZnCl_2$ to one part NaCl ; (*e*) water-quenching or air-cooling ; (*f*) fine-tinning at 270° C. in pure tin under a flux of palm oil. For this operation the work is loaded on special jigs of chromium-plated mild steel ; (*g*) quenching in kerosene or Shell No. 12A light quenching oil ; (*h*) finishing by vapour-degreasing or branning.

Tin coatings of satisfactory brilliance, good continuity, and 0·00075 in. thickness are obtained.—J. P. S.

Tin Coatings on Metals. F. W. Bogert. (Metal Finishing, 1948, vol. 46, Jan., pp. 68–71). The hot-dip and electrolytic processes of tinning are briefly described.—R. A. R.

A Detailed Description of the New Continuous Electrotinning Plant Now in Operation at the Ebbw Vale Works of Richard Thomas & Baldwins Ltd. D. G. P. Paterson. (Sheet Metal Industries, 1948, vol. 25, Feb., pp. 311–320).

The Metal-Spraying Process. G. Schulz. (Werkstatt und Betrieb, 1948, vol. 81, Jan., pp. 17–18). A description is given of the metal-spraying process and the Schoop pistol used for it.—R. A. R.

Metal Spraying by the Wire Process. W. E. Ballard. (Journal of the Birmingham Metallurgical Society, 1948, vol. 28, Mar., pp. 37–42). The author presented a film on metal spraying by the wire process, and in his introductory remarks explained why the process has developed into an important industry. The text of the commentary to the film is also given.—R. A. R.

The Metallizing Process. R. Mansell. (Steel Processing, 1947, vol. 33, Dec., pp. 742–745, 765; 1948, vol. 34, Jan., pp. 23–25, 44). The metallizing or metal-spraying process, its advantages and many of its applications are described.—R. A. R.

German Metal Spraying Techniques. (British Intelligence Objectives Sub-Committee, 1948, Report No. 1541: H.M. Stationery Office).

Phosphate and Colored Plastic Coatings. G. H. Pimbley. (Organic Finishing, 1947, vol. 8, Nov., pp. 9, 13, 15, 17, 64). This is a discussion of the use of phosphate and coloured plastic coatings for the protection and decoration of metals.

The Phosphate Treatment of Metals before Painting. H. A. Holden. (Journal of the Oil and Colour Chemists Association, 1947, vol. 30, Mar., pp. 61–72: [Abstract]. Chimie et Industrie, 1948, vol. 59, Mar., p. 268). Metallic surfaces (iron, steel, zinc, or cadmium), show a great resistance to corrosion when hot-coated with an aqueous solution, consisting mainly of free phosphoric acid and phosphate of zinc, manganese, or iron (or a mixture of these salts). This process facilitates the adhesion of paint to the metal and also protects it, as the corrosion remains local and does not spread under the paint coatings if some of the metal becomes exposed after severe handling. This process was used to a great extent in Germany during the war and it now has many applications in the United States.

Low Temperature Phosphate Coating for Steel Easily Applied. N. P. Gentieu. (Material and Methods, 1948, vol. 27, Feb., pp. 74–75). A brief statement is given of a cold spray process known as "Granodizing" by which a steel surface, after preparation, can be coated with zinc phosphate.—R. A. R.

A New Chemical Coating to Protect Metals. (Chemical Industries, 1946, vol. 59, Dec., p. 1001: [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 32). The coating, composed of butyral polyvinyl, alcohol, and phosphoric acid, was developed by the Bakelite Corporation during the war. The product, which is applied cold and used as an undercoat, consists of a solution of butyral polyvinyl in alcohol, with phosphoric acid at a concentration of 30–50% of the weight of dissolved resin.

Clear Coatings with Rust Preventive Properties. H. Sellei and E. Lieber. (Corrosion and Material Protection, 1948, vol. 5, Jan.–Feb., pp. 10–12, 22). The authors review the background and initial development of transparent and readily removable coatings for packing metal parts.—R. A. R.

Organic Coatings for Corrosion Protection. A. G. Gray. (Products Finishing, 1948, vol. 12, Feb., pp. 44–54). The author reviews a paper by G. W. Seagren before the Mellon Institute of Industrial Research entitled "Modern Metal Protection" in which the conditions necessary for the successful use of organic coatings to prevent corrosion are discussed.—R. A. R.

Pyrobituminous Organosols. H. C. O'Brien, jun., and W. A. Royston, jun. (Corrosion and Material Protection, 1948, vol. 5, Jan.–Feb., pp. 13–14). The mother substance of the bituminous native asphalts occurs naturally as pyrobitumen which includes Wurtzelite. A protective coating known as "Roskote Resin" has been prepared from Wurtzelite, the constitution and properties of which are discussed.

Strippable Plastic Coating Protects Surface Finishes. A. G. Gray. (Products Finishing, 1948, vol. 12, Jan., pp. 54–58). The use of easily removable plastic coatings to prevent damage to stainless steel during pressing and drawing operations is discussed.—R. A. R.

Research in the Porcelain Enamel Industry. G. H. Spencer-Strong. (Ohio State University, Engineering Experiment Station News, 1947, vol. 19, Apr., pp. 38–42). The base metal used for porcelain enamelling is normally sheet iron or cast iron, although very small amounts of copper and the precious metals are also used. Experiments are at present being conducted on sheet iron that will need only one enamel coat.

Ceramic Coatings for High-Temperature Protection of Steel. G. C. Close. (Steel Processing, 1947, vol. 33, Dec., pp. 751–754). The results of experiments by W. N. Harrison, D. G. Moore, and J. C. Richmond on the development of an enamel frit for coating aircraft engines exhaust pipes are presented and discussed. A good coating was developed and the results of flame-impingement, thermal-shock, and oxidation tests on it are given.—R. A. R.

Stove Enamelling Car Bodies in Gas-Fired Ovens. (Industrial Gas Times, 1947, vol. 10, July, pp. 320–326; Aug., pp. 342–344, 360). An illustrated description is given of a long gas-fired oven designed by the Chrysler Corporation for baking synthetic-resin finishes on motor-car bodies.—R. A. R.

Determination of Compressive Stress Present in Porcelain Enamel on Sheet Iron. E. E. Bryant and M. G. Ammon. (Journal of the American Ceramic Society, 1948, vol. 31, Jan. 1, pp. 28–30). A method for determining comparative compressive stress produced in porcelain enamel on sheet iron is described. The method consists of preparation of laboratory samples under carefully selected and controlled conditions and measurement of the warpage produced in the sample due to application of enamel on one side. Data obtained by the above method are compared with expansion curves. It is concluded that expansion curves on frit samples are not a satisfactory means of evaluating compressive stress in the porcelain enamel coating on sheet iron.—R. A. R.

New Synthetic Finish for Ferrous and Nonferrous Metals. C. L. Shapiro. (Materials and Methods, 1948, vol. 27, Jan., pp. 62–64). Particulars are given of the properties of vinyl-type coatings for metals.—R. A. R.

Report on the Evaluation of Surface Treatment of Steel Prior to Painting. A. J. Eickhoff. (ASTM Bulletin, 1948, Jan., pp. 77–80). This is the final report on outdoor exposure tests conducted by a sub-committee of A.S.T.M. Committee D-1 to determine the effect of cold phosphate/phosphoric-acid treatments of steel surfaces before subsequent painting.—R. A. R.

Effect of the Physical-Chemical Properties of the Pigments on the Corrosion-Resistant Film. H. Wagner. (Archiv für Metallkunde, 1947, vol. 1, Oct., pp. 439–444). An investigation is described in which paints were pigmented with red lead, iron powder, micaceous

iron ore, and aluminium powder, and the corrosion-preventive properties of the paints were tested. In the finely divided state all these materials produced paint films with good protective properties, but agglomeration resulted in only the outer portion of the pigment being effective so that some pigment was wastefully used. With flaky pigments a filling material is required, but another method was examined, namely, the use of "core pigments" which consist of particles of inert material surrounded by the corrosion-resistant colouring material. Different methods of producing these core pigments are described.—R. A. R.

The Mechanism of Pigmentation. H. Wagner. (Archiv für Metallkunde, 1947, vol. 1, Oct., pp. 448–452). The electrochemical effects of pigments are discussed. These effects are not of very great importance with regard to the behaviour of the paint, but they do have some influence on the ageing of the paint film.—R. A. R.

Protection against Corrosion by Emulsions. H. F. Sarx. (Archiv für Metallkunde, 1947, vol. 1, Oct., pp. 455–456). The production of emulsions and their value in the protection of metals against corrosion are discussed.—R. A. R.

New Methods of Drying Lacquers. A. Merz. (Archiv für Metallkunde, 1947, vol. 1, Oct., pp. 456–460). The drying of lacquer coatings on metals by electrical resistance, induction and radiation is discussed.—R. A. R.

Notes on the Chemical Testing of Paints. G. Zeidler. (Archiv für Metallkunde, 1947, vol. 1, Oct. pp. 462–464). Methods of analysing pigments, solvents, binders, and oils in paints are discussed.—R. A. R.

The Erichsen Drawing Test and the Mandrel Bend Test as Methods of Investigating Paints. W. König. (Archiv für Metallkunde, 1947, vol. 1, Oct., pp. 460–462). The stress imposed on a paint film when a painted metal strip is bent over a mandrel is greater than in the Erichsen test, and the former test requires no expensive equipment. Data relating the results of the two methods of testing are presented.—R. A. R.

Electrolytic Action of Metallic Pigment in Protective Paints. J. E. O. Mayne. (Paint, 1947, vol. 17, Nov., pp. 380–382; [Abtract]. Chimie et Industrie, 1948, vol. 59, Apr., p. 379). Metallic pigments can be classified as cathodic when they tend to further corrosion, *e.g.*, copper, bronze, tin, and lead, or anodic when they have greater negative potential than iron and are capable of preventing corrosion, *e.g.*, aluminium, magnesium, and zinc. Anodic pigments used in paints enable the conductivity of films and the electrode potential to be measured. Paints containing zinc possess an appreciable conductivity, which is not the case for those containing aluminium or magnesium. The electrode potential of steel samples coated with zinc paints is comparable with that of pure zinc samples and, after partial immersion for three months, the protected samples did not show the slightest trace of rust. Paints rich in zinc are therefore capable, under certain conditions, of giving good cathodic protection to steel. The film of zinc oxide covering the metal is not comparable with the similar film covering aluminium or magnesium, and it acts to a certain extent as a good electric conductor.

Action of Antifouling Paints. B. H. Ketchum. (Industrial and Engineering Chemistry, 1948, vol. 40, Feb., pp. 249–253). An anti-fouling paint which depends on copper or one of its compounds dissolves in an alkaline glycine solution about 100 times as fast as in the sea. The results of immersion for three days in the glycine solution predict whether the paint will maintain a copper leaching rate adequate to prevent fouling when immersed in the sea. Satisfactory results are obtained with paints containing metallic copper or cuprous oxide as a toxic whether the paint depends on a soluble matrix or on continuous contact of toxic particles to permit the toxic release. This accelerated test permits the elimination of unsatisfactory formulations without time-consuming and expensive exposures in the sea. A large number of variations of a given paint formulation can thus be evaluated quickly.

Anti-Fouling Paints. H. Rabaté. (Peintures, Pigments,Vernis, 1948, vol. 24, Apr., pp. 114–119). The theories concerning anti-fouling paints are reviewed and the different types of paints compared.—R. F. F.

Suitability of Red Lead for the Protection of Ship's Bottoms. M. Chardome. (Peintures, Pigments-Vernis, 1948, vol. 24, Feb., pp. 42–45). The work of various investigators on the use of red lead for the protection of ships' bottoms is reviewed.—R. F. F.

POWDER METALLURGY

Production and Uses of Iron and Other Metal Powders. (Chemical Age, 1947, vol. 56, May 17, pp. 641–642 [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 34). The following processes for the production of iron powder are outlined: Electrolytic deposition, atomization, crushing, and reduction. Analyses and photomicrographs are given.

Preparation of Metallic Powders by Electrolysis of Salt Baths. Andrieux. (Société Française de Métallurgie: Journal du Four Electrique, 1948, vol. 57, Jan.–Feb., pp. 12–14). The separation of crystals, choice of bath, cathodic condition, and the electrolytic process in the production of metal powders are discussed. —R. F. F.

Powder Metallurgy. (Echo des Mines, 1947, Dec., pp. 212–214). Modern practice in the manufacture of powdered metals is reviewed.—R. F. F.

Powder Metallurgy. (Chemical Age, 1947, vol. 57, July 19, pp. 93–94: [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 34). Recent progress in powder metallurgy in England is outlined. The history, methods of production, properties of metal powders, and the production of hard-metal carbides are reviewed.

Powder Metallurgy: Nickel Steels. Laurence Delisle and W. V. Knopp. (Société Française de Métallurgie: Revue de Métallurgie, 1947, vol. 44, July–Aug., pp. 245–255). Samples were prepared from powders capable of passing through a sieve with a mesh of 45 microns. Those samples were of three compositions, the first a 0·4% carbon steel as a standard comparison; the second containing 0·4% of carbon and 3·50% of nickel, and the last equivalent to steel S.A.E. 2330. Tests were carried out on these samples to show the effect of temperature and time of heating, and amount of nickel and other constituents on the mechanical properties. The diffusion of nickel is sufficient to alter radically the properties of the steel, but not sufficient to produce a completely homogeneous steel. The microstructure of these nickel steels consists of a martensitic core in a pearlite matrix.—R. F. F.

German Methods for the Manufacture of Iron Powder Cores. (British Intelligence Objectives Sub-Committee, 1948, F.I.A.T. Final Report No. 1101: H.M. Stationery Office).

German Tungsten Carbide Wire, Bar, and Tube Drawing Dies. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1711: H.M. Stationery Office). Details are given of German methods of manufacturing tungsten carbide alloys and fabricating

them into dies for drawing wires, tubes, and bars, and into tools and wear-resisting parts are described.—R. A. R.

Materials Resistant to Wear and High Temperatures. New Applications of Powder Metallurgy. P. Schwarzkopf. (Société Française de Métallurgie, Oct. 24, 1946 : Revue de Métallurgie, 1947, vol. 44, Sept.–Oct., pp. 267–270). The resistance of metals to wear and to high temperatures is discussed. Metals having a high melting point normally have good resistance to wear and metallic-powder compacts are found to be especially suitable when either or both these properties are required. The work done by various investigators on refractory materials is discussed.—R. F. F.

The Effect of Particle Size on the Electrical Properties of Sintered Materials. H. H. Hausner. (Powder Metallurgy Bulletin, 1948, vol. 3, Jan., pp. 4–8). The general theory of the relationship between the electrical properties of sintered materials and the particle size of the compacts is explained, and an investigation with non-ferrous metal compacts is described, the results of which were in agreement with the theory.—R. A. R.

Sieve Test of Metal Powders. R. E. Pollard. (Journal of Research of the National Bureau of Standards, 1947, vol. 39, Dec., pp. 487–505). Reproducible results were obtained in sieve tests of sponge iron, electrolytic iron, electrolytic copper, and nickel when certain variables affecting the sieving characteristics of the powders were eliminated or controlled. One of these was a cumulative sampling error resulting from repeated riffle cutting of limited powder supplies. Another was the effect of exposure of the powder to humid atmospheres. The effects of both variables were demonstrated in tests with sponge iron. Variations of considerable magnitude were observed when either variable was uncontrolled. Significant variations also were noted when the same powders were sieved with different sets of certified sieves. These differences were reduced considerably in magnitude when comparisons were made on the basis of the size of the average opening as determined during the certification tests instead of the nominal sieve opening. Development of more effective methods for controlling these variables or evaluating their effects would improve the reproducibility of sieve tests.

Sieve Analyses of Powdered Metals Affected by Atmospheric Humidity. (Steel, 1948, vol. 122, Feb. 23, pp. 89–90, 116). Results obtained by the Bureau of Standards in investigations of the effect of atmospheric humidity on the screen analysis of powdered metals are reported and discussed.—R. A. R.

Industrial Applications of the Powder Metallurgy Process. A. J. Langhammer. (Stevens Institute of Technology : Metal Progress, 1948, vol. 53, Mar., pp. 387–389). Some developments in powder metallurgy achieved by the Chrysler Corporation, such as the manufacture of heavy-duty self-lubricating bearings, and parts of unusual shape, are described.—R. A. R.

Permanent Magnets of Sintered Oxides. R. J. Studders. (Product Engineering, 1948, vol. 19, Feb., pp. 120–122). The manufacture of permanent magnets by powder metallurgy using mixtures of Fe_2O_3, Fe_3O_4, and CoO is described and data on the magnetic properties are given.—R. A. R.

PROPERTIES AND TESTS

Mechanical Tests on Miniature Test Pieces. P. Chevenard. (Métaux, Corrosion, Usure, 1943, vol. 18, June, pp. 107–109). The merits and demerits of using miniature test-pieces for mechanical tests are discussed.—J. C. R.

The Effect of Normalising on the Micro-Structure and Tensile Properties of Welded Metal. G. A. Keay. (Admiralty, Naval Construction Research Establishment, Report No. N.C.R.E./R.32 (June 1947), A.C.S.I.L./A.D.M./47/639 : Journal of the British Shipbuilding Research Association, 1948, vol. 3, Mar., p. 104). Some samples of welded mild-steel plates were stress-relieved at 660° C. and other samples were normalized at 900° C. The microstructures of these samples were examined and compared with those samples from the same welded plates which had received no heat-treatment subsequent to welding. Further samples, some in the as-welded condition and others after normalizing at 900° C., were subjected to tensile tests. The results showed that the effect of normalizing on welded mild-steel plates is to refine and make more uniform the structure of the weld, at the same time relieving the parent metal of the structural alterations due to the heat of welding. On normalizing, the tensile properties of the weld metal approach those of the parent metal, but, with the combination of parent metal and welded rods tested, the yield of the weld metal is still, in general, considerably higher than that of the parent plate. This may have a very marked adverse effect on the behaviour of a welded plate deforming under explosive loading. Details are given of the composition of both the steel and weld deposits, as well as of the welding procedure.

The Effect of Temperature and Welding Conditions on the Strength of Large Welded Tubes. G. E. Troxell, E. R. Parker, H. E. Davis, and A. Boodberg. (Welding Journal, 1948, vol. 27, Feb., pp. 34-s–49-s). This paper describes the methods of testing and presents the results of tests on twelve welded 20-in. dia. by 10-ft. long tubes made of ship-quality steel. The tubes were formed by welding together two semi-cylindrical pieces of $\frac{3}{4}$-in. thick plate along two longitudinal seams.—R. A. R.

Preloading and Strength Values at Different Deformation Velocities. M. Hempel and H. R. Sander. (Kaiser-Wilhelm-Institut für Eisenforschung : [Abstract]. Stahl und Eisen, 1948, vol. 68, Jan 1, pp. 25–26). The effects of different rates of plastic elongation on the tensile strength of the deformed steel specimens were examined. In general, increasing the rate of plastic deformation increased the tensile strength.—R. A. R.

Slow Bend Test on Notched Micro-Specimens. L. Colombier. (Comptes Rendus, 1948, vol. 226, Feb. 23, pp. 629–631). The slow bend test has been used to determine the quality of structural steels produced under laboratory conditions from very pure raw materials. Notched microspecimens were prepared from metal which had been rolled and then heat-treated. Slow bend test results agreed closely with those of impact tests previously carried out, but it was not possible to indicate temper brittleness or the phenomena resulting from overheating. Despite this limitation the slow bend test is considered to be an excellent method for studying steels produced under the most perfect conditions.—J. C. R.

The Yield Point in Bending and the Stress Distribution in Bars and Tubes in Plastic Bending. E. Bernhult. (Iron and Steel Institute, 1948, Translation Series, No. 338). This is an English translation of a paper which appeared in Jernkontorets Annaler, 1943, vol. 127, No. 10, pp. 491–533. *See* Journ. I. and S.I., 1944, No. I, p. 101A.—R. A. R.

A Study of the Effect of Variations in Notch Depth and Notch Root Radius on the Izod Values of B.S. 3S1 Steel. F. G. Lewis. (Council of Scientific and Industrial Research, Australia, Division of Aeronautics, 1947, Structures and Materials Note 159). Three-notch

Izod specimens of British Standard 3S1 manganese–silicon steel were designed so that all possible combinations of two notch depths and two root radii could be tested at 0°, 25°, and 50° C. Notch depth and notch-root radius were shown, as expected, to have significant influence on Izod results, but the scatter of test results for any given test-piece was not related to minor variations of approximately ±0·001 in. in nominal notch dimensions arising from machining errors. When two sets of duplicate standard three-notch specimens were tested it was found that a difference of 20% in mean Izod values did not correlate with minor notch variations or temperature fluctuations. Response to notch variations was not influenced by temperature within the experimental limits.—R. A. R.

The Effect of Combined Stresses on the Transition Temperature for Brittle Fracture. C. W. MacGregor and N. Grossman. (Welding Journal, 1948, vol. 27, Jan. pp. 7-s–16-s). Bending tests were conducted on two carbon steels and a chromium–molybdenum steel at different temperatures and various constant strain rates; they proved that a single type of notched bar will show the same embrittlement temperature at the same effective strain rate as a circular disc of the same material freely supported and centrally loaded. The effect of the ratio of combined stresses on the embrittlement temperature was determined for a 0·20% carbon steel.—R. A. R.

A Comparison of the Brittle Transition Temperatures as Determined by the Charpy Impact and the M.I.T. Slow Bend Tests. C. W. MacGregor and N. Grossman. (Welding Journal, 1948, vol. 27, Jan., pp. 17-s–19-s). A set of slow bend and Charpy impact tests are described which were carried out on three different steels to compare the temperatures of transition to brittle fracture at the same deflection rates as determined by both types of tests. The experimental results show that the slow bend tests predict transition temperatures which lie on the upper knee of the Charpy **S**-curve shortly before the sudden fall in energy values.—R. A. R.

The Criterion of "Yield" of Gun Steels. J. L. M. Morrison. (Institution of Mechanical Engineers, 1948, Mar. 12, Advance Copy). This paper describes tests carried out on standard nickel–chromium–molybdenum gun steel in the form of bar material and in the form of gun-barrel forgings, and on seven alternative gun steels in the form of forgings produced experimentally during the 1939–45 war, with the object of determining the criterion of "yield" of these materials. The standard gun steel in the form of bar material gives a drop in stress at yield—the same steel in the form of forgings does not, nor do any of the alternative steels. In the first case, the criterion for the occurrence of the initial yielding is found to be the existence of a critical maximum shear stress; plastic flow continues in accordance with the Mises-Hencky criterion. In all the other steels the plastic flow occurs and continues in accordance with predictions based on the Mises-Hencky criterion. A brief additional note compares these results with those of earlier work, and draws attention to an earlier theoretical analysis which offers an explanation of them.

The Examination of Surfaces by the Solex Pneumatic Method. (Métaux, Corrosion, Usure, 1943, vol. 18, Mar., pp. 55–57). Brief details are given of the Solex micro-measuring appliance for the examination of surfaces.—J.C. R.

Orientation of Strain Gages in Stress Analysis. A. W. Rankin. (General Electric Review, 1947, vol. 50, Sept., pp. 14–21: Electrical Engineering Abstracts, 1948, vol. 51, Jan. p. 6). Having recapitulated the theory of two-dimensional stress systems, the author applies it to deduce the number of strain gauges required to determine the principal stress in various cases.

Photoelastic Analysis of Stresses in Crane Ladle Hooks. F. K. Chang, K. E. Knudsen, and B. G. Johnston. (Iron and Steel Engineer, 1948, vol. 25, Jan., pp. 87–94). Stresses under load in five ladle hooks of typical design were investigated by photo-elastic analysis of models constructed of clear bakelite carefully polished and machined to the required dimensions. The tests showed that the Winkler theory for curved beams, as modified by an equation and coefficients given in the paper, gives a reasonably good approximation to the maximum tensile stress on the inside curved portion of a ladle hook and that, for loads comparable with those used in the trials, reduction in weight could be safely effected in four of the designs by lessening the area of the straight section of the shank.—J. R.

The Effect of Shape and Size Factors on the Fatigue Strength. N. N. Aphanasiev. (Institute of Practical Engineering of the Academy of Science, U.S.S.R., 1946, pp. 157–167: Engineers' Digest, 1948, vol. 9, Mar., pp. 96–100).

The Alternating Tensile Fatigue Strength of Similarly Notched Steel Specimens of Different Diameters. F. Bollenrath and H. Cornelius. (Metallforschung, 1947, vol. 2, Jan., pp. 9–11). According to F. K. Th. van Iterson the stresses which, in notched tensile-test specimens, lead to the beginning of plastic flow depend upon the notch angle and the section at the root of notch, and are independent of the notch depth. This theory was tested by making alternating tensile tests on notched specimens of two heat-treated carbon steels with notch-root diameters of 5, 12, 18, and 25 mm. and notch-root radii of 1 and 0·1 mm. The results confirmed the validity of the theory.—R. A. R.

A Micro-Indenter for Use with a Metallurgical Microscope. T. A. Crawshaw. (Journal of Scientific Instruments, 1948, vol. 25, Jan., pp. 13–14). A simple device is described which can be attached to a metallurgical microscope in order to make small impressions with a standard Vickers pyramid diamond.—R. A. R.

Approximate Relationships Between Case Depth and Rockwell Hardness. B. R. Payne, jun. and L. S. Stutts. (Western Metals, 1947, vol. 5, pp. 29–30: Chemical Abstracts, 1948, vol. 42, Feb., 10, p. 853). Tests show that it requires the following case depths to support the various hardness scales. For Rockwell 15 N a case depth of 0·003 in. is required, for Rockwell 30 N 0·007 in., for 45 N 0·009 in., for Rockwell A 0·010 in., for D 0·017 in., and for C 0·019 in.

Fundamentals of Annealing Low Carbon Steel. G. Sachs, L. J. Ebert, A. W. Dana, and M. J. Jones. (Iron and Steel Engineer, 1948, vol. 25, Jan., pp. 98–100). Data available from an earlier investigation of the relationship between mechanical properties and other factors in the annealing of low-carbon steel strip are used in an examination of hardness and grain-size and show the relative effects of different time/temperature combinations. (*See* Journ. I. and S.I., 1947, vol. 156, Apr., p. 631).—J. R.

Contribution to the Study of Pickling Embrittlement of Iron. G. Chaudron and L. Moreau. (Métaux, Corrosion, Usure, 1943, vol. 18, Mar., pp. 43–48). Polycrystalline and monocrystalline pure iron sheets after being rolled down from 0·8 to 0·3 mm. were charged with hydrogen by pickling and by electrolysis. Their hardness and tensile strength were noted after varying periods and their appearance examined by micrographs to note any trace of pockets of hydrogen. Similar tests were carried out on specimens under tension. Work-hardened monocrystalline iron specimens behaved as polycrystalline

metal, and hydrogen pockets were formed. When a single crystal, perfectly annealed, was subjected to tension almost to its elastic limit during pickling, brittleness and hydrogen pockets appeared.—J. C. R.

Hydrogen Embrittlement in Oxyacetylene Pressure Welding ? K. B. Young and H. J. Nichols. (Welding Journal, 1948, vol. 27, Jan., pp. 30-s–32-S). Oxy-acetylene welding has been applied to join the ends of concrete reinforcing bars made by rerolling scrap rails of 0·79% carbon steel. Brittle joints were encountered. An investigation of the cause is described. Local heating with a slightly reducing flame induced brittleness, and analysis indicated that the hydrogen content of the steel had been increased. The ductility was restored by annealing.—R. A. R.

The Chip-Formation Properties of Lead-Bearing and Lead-Free Free-Cutting Steels. A. Schepers and R. Krauss. (Stahl und Eisen, 1948, vol. 68, Feb. 26, pp. 90–91). The results of cutting tests indicated that the addition of lead to very low carbon steel does not produce machinability equal to that of a free-cutting steel, and that the ordinary sulphur-bearing free-cutting steel has better machinability than an ordinary steel of equal hardness to which lead has been added.

Apparatus for the Rapid Taking of Magnetization Curves. K. P. Belov and G. M. Strakhovskij. (Zavodskaja Laboratoriya, 1946, No. 6, pp. 577–582 : Engineers' Digest, 1948, vol. 9, Mar., pp. 85–87).

Some Notes on the Barkhausen Effect. V. Šebesta. (Hutnické Listy, 1948, vol. 3, No. 1, pp. 14–15). [In Czech]. The Barkhausen effect was found to be less pronounced in iron wires coated with non-magnetic material.

Control of Permanent-Magnet Alloy Quality. J. D. Seaver and R. E. Anderson. (General Electric Review, 1947, vol. 50, Oct., pp. 44–47 : Nickel Bulletin, 1948, vol. 21, Jan., p. 9). Magnets made from Alnico-type alloys, which are neither ductile nor malleable, are cast directly into their final shape from small furnaces. This technique raises the problem of maintaining constant the magnetic quality of very small heats of material. In this paper, the authors describe the most obvious method of control, namely, direct measurement of the magnetic properties. Equipment developed, technique used, and the actual performance in a typical foundry producing magnets for measurement purposes are reviewed. In the manufacture of Alnico V a charge of relatively pure alloying elements (iron, nickel, cobalt, copper, aluminium) and clean remelt scrap of known composition, is melted in a high-frequency furnace. No refining operations are usually carried out, the melted alloy being poured, either directly or by the use of smaller ladles, into baked or green-sand moulds, to form the individual magnet castings. After solidification and cooling, the castings are broken out of the moulds, cleaned to remove sand, heat-treated, ground and machined, and finally tested for magnetic quality before being assembled into the final equipment. The various methods of control that may be used include (*a*) chemical analysis of each heat, (*b*) testing of several magnets from each heat, (*c*) determination, with search coil and galvanometer, of flux-output of a small bar cast from each heat, and (*d*) determination of the demagnetization curve of a test-bar from each heat. The comparative merits of each of these methods are discussed. In the West Lynn works of the General Electric Co. a simplified test based on (*d*) is employed, by testing the maximum energy point only, or, more precisely, the remanence in a predetermined demagnetizing field. Generally only one point in the demagnetization curve is necessary, additional points being taken only when material is of questionable quality. A permeameter suitable for determining demagnetization curves of materials of high coercive force is briefly described, and a circuit diagram illustrating the simplified test-procedure is shown. It is reported that the control method described has worked satisfactorily over a period of four years and that relatively untrained foundry operators may be used.

Supersonic Image Generator for Metallographic Investigation. (British Naval Gunnery Mission, Special Technical Report No. 11 : Journal of the British Shipbuilding Research Association, 1948, vol. 3, Feb., pp. 90–91). The device described was invented by R. Pohlman. The principles of the method were described in Zeitschrift für Physik, 1939, vol. 113, p. 697 and 1937, vol. 107, p. 497, and in Research and Progress, 1941, vol. 7, p. 71. Supersonic waves, of a frequency from 3 to 7 Mc./sec., generated by a quartz crystal, are brought to a focus by an acoustic lens after passing through the material under test. The detector consists of a cell containing xylol in which very small particles of metal are suspended. These will arrange themselves in planes parallel to the wave fronts; therefore, where the material is uniform, light will be reflected from the regular plane surface, and the image will be bright, but any discontinuity in the material will distort the wave fronts, and the image will appear dark.

A brief description is given of the instrument itself and its mechanical operation. It is claimed that the apparatus is very simple to handle. Special units have been designed for the quick investigation of round bodies (shell cases) about 2 in. in dia. and for seams of very large dimensions. There is no limit to the thickness of material which can be handled, the resolution being unaffected by this factor. Curved surfaces can be dealt with satisfactorily provided the radius of curvature is not less than approximately 2 in. Below this value, the difficulty of interpretation increases very rapidly with decrease in radius, becoming impossible at values less than 0·1 in.

X-Ray Diffraction Cameras for Metallurgical Specimens. D. W. Davison. (Journal of Scientific Instruments, 1948, vol. 25, Jan., pp. 7–10). In designing the cameras described, the aim has been to provide certain facilities which are particularly convenient for miscellaneous work on industrial specimens. At the same time maximum use has been made of straightforward design, and of materials easily obtainable. Two types of camera are described, one for "grazing-incidence" and the other for back-reflexion.—R. A. R.

Radiography in the Foundry. R. Jackson. (Metalen, 1948, vol. 2, Mar., pp. 131–151). Progress in Great Britain in the use of radiography in the foundry, particularly the steel foundry, is reviewed. All kinds of casting defects, their removal, and the influence of the defects on the strength of castings are discussed.—R. A. R.

X-Ray Investigations in the Service of Foundry Research. A. Swagerman. (Metalen, 1948, vol. 2, Mar., pp. 151–156). [In Dutch]. The hesitation to apply radiography in Dutch foundries is compared with the progress made in the United States. Its possibilities are outlined, and the need for a central X-ray laboratory in Holland is stressed.—R. A. R.

Radiographs of Castings. D. J. Binkhorst. (Metalen, 1948, vol. 2, Mar., pp. 156–158). [In Dutch]. Methods of dealing with scattered radiation and difficulties in radiography caused by casting shape are discussed. The use of short-wave X-rays generated in high-voltage tubes is advocated.—R. A. R.

The Possibilities of X-Ray Investigations in the Foundry. L. van Ouwerkerk. (Metalen, 1948, vol. 2, Mar., pp. 159–163). [In Dutch].

Laboratory for Mechanical Testing at Very Low Temperatures. J. L. Zambrow. (Ohio State University, Engineering Experiment Station News, 1947, vol. 19, Dec., pp. 4–9). The laboratory of the Ohio State University is described.

Alloys for Severe High-Temperature Service. W. C. Leslie and D. J. McPherson. (Ohio State University, Engineering Experiment Station News, 1947, vol. 19, Dec., pp. 42–47). Particulars are given of experimental work at Ohio State University on Timkin 16-25-6 alloy (chromium–nickel–molybdenum steel) and on chromium–titanium binary alloys.

Alloys for Gas-Turbine Blades. A. Semkowicz. (Hutnik, 1947, vol. 14, Mar., pp. 142–149). [In Polish]. Particulars of the alloys used for gas-turbine blades and other parts are given. Alloys recently used in the United States, Great Britain, and Germany are included.—W. J. W.

Rupture Testing in a 48-Bar Furnace. J. D. Nisbet. (Iron Age, 1948, vol. 161, Feb. 12, pp. 81–82). A description is given of a furnace and equipment with which creep tests can be carried out simultaneously on 48 specimens.—R. A. R.

Gases in Metals and Their Determination. H. Nipper. (Gjuteriet, 1948, vol. 38, Feb., pp. 23–29, 35). [In Swedish]. The author discusses the different ways in which gases occur in metals (*i.e.*, in solution, trapped, and as chemical compounds), as well as the effect of temperature and pressure on the amount dissolved, the effect of the gas on the properties of the metal, the mechanism of gas adsorption and the diffusion of gases in metals. Methods of determining the gases and the quantity present are described.—R. A. R.

Diffuson in Solid Metals. A. Bielański. (Hutnik, 1946, vol. 13, Dec., pp. 603–611). [In Polish]. The reactions occurring during diffusion in solid metals are discovered. The diffusion constants and the activation energy for different metals and conditions are listed. Three types of diffusion are dealt with.—W. J. W.

The Effect of a Third Element on Diffusion in Metals. J. Hauk. (Metallforschung, 1947, vol. 2, Feb., pp. 49–55). The literature on the effect of a third element on the diffusion in metals is reviewed. Greatest attention is given to the diffusion of carbon in iron, but the diffusion of nitrogen, phosphorus, manganese, nickel, copper, beryllium and zinc in iron, and the effect of carbon on the diffusion of many alloying elements in iron are also dealt with. There are 56 references.—R. A. R.

The Influence of Aluminium on Steels and Cast Irons. (Study of Iron–Aluminium and Iron–Aluminium–Carbon Alloys). J. R. Maréchal. (Métaux, Corrosion, Usure, 1943, vol. 18, Apr., pp. 65–68; May, pp. 82–96). A review of the influence of aluminium on steels and cast irons is presented under the following headings: Deoxidation of steels by aluminium; aluminium steels and their structure; aluminium cast irons and their structure; influence of aluminium on the mechanical properties of cast irons; the expansion of aluminium cast irons; resistance to thermal shock of aluminium cast irons; corrosion resistance of aluminium cast irons; advantages and demerits of aluminium cast irons; ferro-aluminium; and alloys with a very high aluminium content.—J. C. R.

Use of Carbide-Stabilizing Elements to Improve Weldability of Plate Steels. F. F. Franklin. (Welding Journal, 1948, vol. 27, Jan., pp. 20-s–26-s). The manner in which stabilizing elements, particularly vanadium, affect welding, and how they can be utilized to improve the welding properties of low-alloy high-strength steels, are discussed.—R. A. R.

Spring Design and Manufacture. J. A. Roberts. (Wire Industry, 1948, vol. 15, Jan., pp. 43–47; Feb., pp. 109–112). A brief account is given of the testing of spring wire, and calculations for the design of springs are explained.—R. A. R.

METALLOGRAPHY

Some Problems of the Metallic State. Sir Lawrence Bragg. (Swansea and District Metallurgical Society: Iron and Steel Institute, 1948, Special Report No. 39, pp. 5–7). *See* Journ. I. and S.I., 1946, No. I, p. 12A.

A Recent Improvement in the Technique of the Examination of Metals by the Electronic Microscope. J. Bénard. (Métaux, Corrosion, Usure, 1943, vol. 18, Mar., pp. 48–49). An account is given of the examination of metal surfaces coated with a solution of collodion in amyl acetate, using an electron microscope.—J. C. R.

The Presentation of Relief in the Ultra-Microscope by Means of Pressed and Double-Layer Replicas. Johanna Hunger and R. Seeliger. (Metallforschung, 1947, vol. 2, Mar., pp. 65–69). Two developments in the methods of preparing replicas of metal surfaces for use in the electron microscope are described. In the first, the replica is made by pressing aluminium of very high purity on to the specimen; the aluminium is then subjected to an electrolytic oxidation process and an aluminium oxide replica is obtained. In the second, an oxide or pressed replica is coated with thin lacquer; this combines the advantages of the stability of the oxide method with the sharpness obtained by the lacquer technique; in addition, either a positive or negative replica can be obtained.—R. A. R.

A Method of Isolating Carbide and Nonmetallic Particles of a Steel Specimen in Their Original Distribution. A. Skapski and C. Benedicks. (Arkiv för Kemi, Mineralogi och Geologi, 1946, vol. 23A, No. 12). An apparatus and technique, which are described in detail, have been developed for removing the metal of a thin steel sheet by volatilization with very pure chlorine at 600° C., and leaving the inclusions on a silica slab in the original positions. The manganese chloride was very difficult to volatilize, but it was done by subsequent heating in an atmosphere of HCl. The carbon residue which remained formed a network which appeared to correspond to the α-grain boundaries. Many very small particles were observed after removal of the carbon; most of them were Al_2O_3 and they formed a discontinuous network generally of larger size than that of the carbon. The network may be due either to highly dispersed Al_2O_3, or to the decomposition of AlN adsorbed in the grain boundaries.—R. A. R.

Polishing Metallographic Specimens with Pastes Containing Diamond Dust. G. C. Woodside and H. N. Blackett. (Gjuteriet, 1948, vol. 38, Feb., pp. 30–32). [In Swedish]. Detailed descriptions are given of the materials and techniques for polishing metallographic specimens of molybdenum carbide, grey cast iron, hardened alloy steel, and pure molybdenum, using pastes containing diamond dust.—R. A. R.

Macroscopical Determination of Inclusions in Steel. F. Suchonek. (Hutnik, 1947, vol. 14, Apr., pp. 197–203). [In Polish]. Three methods, *i.e.*, the "blue-fracture," step-machining, and micro-examination are compared in connexion with the examination of inclusions in steels. Their limitations are discussed and the standards for the "blue-fracture" method are given.—W. J. W.

Sulphur Prints. W. Loskiewicz and W. Rozanski. (Hutnik, 1947, vol. 14, Feb., pp. 69–76). [In Polish]. The distribution of sulphur in steel can be shown by sulphur prints. The article gives several methods for preparing them, together with much practical advice. The author considers that there is an urgent need for a standard method of sulphur printing.—W. J. W.

X-Ray Analysis: Past, Present and Future. Sir Lawrence Bragg. (Proceedings of the Royal Institution of Great Britain, 1945, vol. 33, Part III, No. 152, pp. 393–400). The author surveys the history of the discovery and applications of X-rays including some details of research work by Sir William Bragg and himself. The future course of pure research with X-ray equipment as a tool is discussed.—R. A. R.

The Austenitic Grain in Steel. P. Bastien. (Métaux, Corrosion, Usure, 1943, vol. 18, Oct., pp. 178–188). The author discusses in detail what is meant by austenite, the structure of the austenitic grain and the factors necessary for its occurrence. The influence of austenitic grain growth on hardening, cementation, mechanical properties, and machinability are considered.—J. C. R.

The Relation between the Hardness of a Worked Metal Surface and the Change in Structure Caused by the Work. K. H. Leise. (Metallforschung, 1947, vol. 2, Apr., pp. 111–114). The microhardnesses of unworked (electrolytically polished) and worked (rubbed with a steel polishing plate) surfaces of single crystals of copper, aluminium, and iron were compared, and for each metal the depth at which the hardness value of the undisturbed metal was again obtained was also determined. Layers of different thickness were also removed from the same surfaces and, by electron-interference technique, determinations were made of the depth at which the effect of mechanical working became so small that the single crystal was visible in the interference picture. The data were in such good agreement that the theory that the cold-work-hardening is due to the reduction in grain-size is confirmed.—R. A. R.

A Note on the Direction of Radial Crystals in Ingots. G. Wranglén. (Jernkontorets Annaler, 1948, vol. 132, No. 2, pp. 57–58). [In Swedish]. An explanation is offered for the fact that the radial crystals which form as an ingot freeze have an upward slope, and a simple electroplating experiment is described which confirms that the crystal tends to grow against the direction of liquid flow. In the case of steel there is a downward flow along the solidifying face.—R. A. R.

Notes on the Problem of Segregation in Ingots. E. Scheil. (Metallforschung, 1947, vol. 2, Mar., pp. 69–75). After reviewing the possible causes of segregation, the author describes a method of calculating the maximum segregation which can occur by reason of the decrease in volume on solidification. Calculations relating to ingots of non-ferrous metals are presented.—R. A. R.

CORROSION

The Role of Diffusion in the Surface Oxidation of Iron. J. Bénard. (Métaux, Corrosion, Usure, 1943, vol. 18, Feb., pp. 25–29). An account is given of an investigation into the rate of oxidation of pure iron at temperatures between 250° and 900° C., and the chemical nature of the films formed. The mechanism of the diffusion of the metal through the oxide film is also discussed.—J. C. R.

Protection against Corrosion. (Petroleum, 1947, vol. 10, Apr., p. 81: [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 39). Coatings used to protect metals against corrosion, and the cathodic protection of pipelines are reviewed.

The Battle Against Corrosion. (Scope, 1948, Feb., pp. 46–57). A review of many methods of combating corrosion is presented.—R. A. R.

The Pulse Polarizer in Corrosion Research. G. A. Marsh. (Corrosion and Material Protection, 1948, vol. 5, Jan.–Feb., pp. 15–20). The use of the "pulse polarizer," in studying electrochemical corrosion phenomena, is described. This instrument applies either a positive or negative potential pulse, of about 2 m.sec. duration to a test electrode, and the potential difference between this electrode (*e.g.*, a calomel half-cell immersed in the same solution) is measured with an electronic voltmeter and high-speed recorder, which plots the depolarization curves. The interpretation of these curves can replace weight-loss measurements, and they can thus be used both for the determination of corrosion rates, and the evaluation of inhibitors. It is suggested that inhibitors be classified by their "McDonald Numbers" defined as the logarithm of the ratio of uninhibited weight-loss to inhibited weight-loss.—M. A. V.

First Report of the Methods of Testing (Corrosion) Sub-Committee. (Journal of The Iron and Steel Institute, 1948, vol. 158, Apr., pp. 463–493).

Practical Corrosion Tests. S. C. Johnson. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy: Australasian Engineer, 1947, Dec. 8, pp. 65–74). The author presents a critical survey of the following types of corrosion tests: (*a*) Electrochemical tests; (*b*) laboratory exposure tests; (*c*) laboratory pilot mill tests; and (*d*) service tests.—R. A. R.

How to Combat Corrosion through Design. E. T. Collinsworth, jun. (Machine Design, 1948, vol. 20, Feb., pp. 116–122; Mar., pp. 142–148). The theory of chemical and electrochemical corrosion is explained and some common examples are described and illustrated. In the second part examples are given of steps which can be taken in machine design to prevent or reduce corrosion.—R. A. R.

Corrosion of Materials by Flue Gas Condensate. F. M. Banks. (Gas, 1947, vol. 23, p. 64: Chemical Abstracts, 1948, vol. 42, Feb. 10, p 856). A review of the literature indicates that most of the investigations of corrosion due to flue-gas condensate fail to duplicate conditions occurring in practice. However, these tests indicate that the 18/13 chromium–nickel stainless steel containing molybdenum shows perfect resistance to flue-gas vapour, the 18/8 steel is excellent up to a certain point after which sudden and severe attack occurs. Next in resistance are lead and then aluminium and copper. Iron is less resistant to flue gas vapours than any of the metals treated. The pitting effect is a very important factor in the failure of stainless steels, chromium steels, and aluminium and its alloys; this is especially true of chromium steels which have not been properly heat-treated.

Utilization of Electrically Insulated Couplings in Corrosion Control. W. F. Levert. (Corrosion, 1948, vol. 4, Jan., pp. 24–28). Experience gained in the control of the corrosion of buried pipelines by electrically insulating some of the joints is recorded.—R. A. R.

Salt Water Spray, Corrosion Test at the Chemical Laboratory of the Etablissement de Recherches Aéronautiques. (Métaux, Corrosion, Usure, 1943, vol. 18, Sept., pp. 170–172). The apparatus used and the operation of the test are described.—J. C. R.

Study of the Dry Corrosion of Metals Using a Thermobalance. P. Chevenard, X. Waché, and R. de la Tullaye. (Métaux, Corrosion, Usure, 1943, vol. 18, July, pp. 121–127). A detailed and illustrated description is given of a thermobalance to be used for studying thin oxide films on corrosion-resistant metals and alloys.—J. C. R.

Mechanical Design Features of Insulated Couplings. P. Williams. (Corrosion, 1948, vol. 4, Jan., pp. 29–31). The design of insulated joints to prevent corrosion in buried pipelines is described.—R. A. R.

Corrosion of Buried Pipes. (Petroleum, 1947, vol. 10, June, p. 133: [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 39). A study is presented of the mechanism of corrosion reactions.

Modern Soil Researches, from the Point of View of the Corrosion of Iron Pipes. C. A. Lobry de Bruin and J. F. Bogtstra. (Gas, The Hague, 1947, vol. 67, Aug. 1, pp. 153–156).

Cathodic Protection of Underground Systems. J. Frink. (Gas Meters Association : American Gas Journal, 1947, vol. 167, Sept., pp. 27–29). The principles of cathodic protection for buried pipelines and other installations are briefly explained.—R. A. R.

Vacuum De-Aeration of Cold Water as a Prevention of Corrosion in Piping. S. T. Powell. (Power, 1947, vol. 91, June, pp. 403–406).

Corrosion Control with Calgon. O. Rice. (Journal of the American Water Works Association, 1947, vol. 39, June, pp. 552–560). Experiments are described which demonstrate that the addition of a sodium phosphate glass to water considerably reduces corrosion by the water, provided it is flowing. In these tests Calgon, containing 67% of P_2O_5, was used.—R. A. R.

The Mechanism of Superficial Oxidation of Iron at Elevated Temperature. J. Bénard. (Réunion du Congrès de l'Avancement des Sciences, Nice, 1946 : Journal de Chimie Physique, 1947, vol. 44, Oct., pp. 266–268). The law governing the rate of growth of each oxide of iron was determined by the following test. Specimens were heated at different temperatures for 5 hr. and the thickness of each oxide was determined with a microscope and the structure of each layer was examined by X-rays. Results show that FeO is dominant below 910° C., but above this temperature, the growth of the higher oxides (Fe_3O_4 and Fe_2O_3) increases rapidly. This change is connected with the change in structure of α-iron to γ-iron at this temperature. Factors affecting the rate of growth of oxide layers are outlined, and the results discussed.—R. F. F.

The Chemical Erosion of Steel by Hot Gases under Pressure. R. C. Evans, F. H. Horn, Z. M. Shapiro, and R. L. Wagner. (Journal of Physical and Colloid Chemistry, 1947, vol. 51, pp. 1404–1429 : Chemical Abstracts, 1948, vol. 42, Feb. 20, p. 1170).

Corrosion: With Particular Reference to Mild Steel and a Note on a New Method of Passifying Blackplate. W. J. S. Roberts. (Proceedings of the Ebbw Vale Metallurgical Society, 1947–48, vol. 1, pp. 59–74). The theory of electrochemical corrosion is explained and simple experiments illustrating it are described. Details are also given of the passivation of blackplate by immersion for 30 sec. at 80° C. in a dilute solution of boric and nitric acids, removal of the reddish deposit, and drying by immersion in hot palm oil.—R. A. R.

The Corrosion of Iron by Caustic Soda Solutions. M. Pourbaix. (Extrait du Bulletin Technique de l'Association des Ingénieurs sortis de l'Université Libre de Bruxelles, École Polytechnique, 1946, pp. 67–86 ; 1947, pp. 109–120). The influences of temperature, concentration, and presence or absence of oxidizing agents upon the rate and type of corrosion of iron and annealed mild steel (piano wire) by NaOH solutions were followed by means of electrode potential measurements against a reversible hydrogen electrode. By plotting these against the NaOH concentrations for a number of different temperatures and studying the polarization curves for both the corroding and electrically insulated specimens, it is shown that corrosion, accompanied by hydrogen evolution, can only proceed under specific ranges of potentials having lower and upper limits characterized by the formation of either violet sodium ferrate or green "sodium ferroate" (FeO_2Na_2) solutions which decompose into a black iron oxide (Fe_3O_4?). Oxidizing agents tend to suppress corrosion by cold dilute NaOH solutions, but enhance it at higher temperatures and concentrations.

The monograph briefly reviews recent theories on the mechanism of caustic embrittlement and produces evidence that corrosion of mild steel in concentrated caustic soda solutions is not intercrystalline in the absence of internal stresses.—N. S.

Relation of Sulfate Bacteria to Corrosion of Steel in Sea Water. R. L. Starkey and J. D. Schenone. (Journal of Bacteriology, 1947, vol. 54, July, p. 46).

The Passivity of Stainless Steels and Adsorption Phenomena. L. Guitton. (Comptes Rendus, 1948, vol. 226, Mar. 8, pp. 805–807). An account is given of experiments with 18% chromium, 10% manganese stainless steel to determine the effect of "sensitization" by immersion in a fluonitric solution prior to passivation. Test-pieces which had received this pre-treatment and others which had not received it, were passivated in a 10% nitric acid solution and then immersed in a 5% oxalic acid solution. Time-potential curves clearly showed the effect of sensitization. Chemical passivity disappeared when an 18% chromium, 10% nickel steel was heated *in vacuo* to 625° C. or an 18% chromium, 10% manganese steel to 435° C. Physical passivity disappeared at ordinary temperatures *in vacuo*. Passivity of stainless steels was considered to be due to adsorption phenomena in all cases. Finally the mechanism of activation brought about by sensitization is discussed. —J. C. R.

Corrosion of Filters in Sugar Refineries. H. Inglesent, J. A. Storrow, and M. Manackerman. (Industrial Chemist, 1947, vol. 23, May, pp. 291–297 ; June, pp. 373–379 ; Dec., pp. 827–833 ; 1948, vol. 24, Feb., pp. 76–84). Measurements have been made on sugar liquors at plant operating temperatures of the differences between electrode potentials of common constructional metals. In general, the metal pairs showed the same polarity at high and low temperatures where ΔE values were large ; they showed considerable difference in their response to changes in temperature. Pumping the liquor over the specimens gave more reproducible results than earlier tests in "stagnant" liquors.—R. A. R.

Unusual Cause and Effect of Corrosion. A. H. Stuart. (Petroleum, 1947, vol. 10, Feb., pp. 26–31 : [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 39). An account is given of an unusual case of corrosion caused by graphite in iron.

The Corrosion of Iron under Protective Films. J. K. Wirth. (Archiv für Metallkunde, 1947, vol. 1, Oct., pp. 445–448). The manner in which osmosis affects the corrosion of iron underneath protective films is discussed. These effect are illustrated by specimens showing the formation and spread of blisters with increasing time of immersion in sea water. The capillary structure of the paint coating plays an important part in the interplay of the many factors causing corrosion. It is desirable to produce a capillary system in the paint which has (*a*) a negative charge in the walls, because then osmosis removes water from the exposed anodic areas of the iron, and (*b*) sufficient volume to permit the water at the cathodic areas, and any hydrogen formed there, to reach the surface.—R. A. R.

The Corrosion of Iron under Protective Films. J. K. Wirth. (Archiv für Metallkunde, 1947, vol. 1, Oct., pp. 452–454). Experiments are described in which films of red-lead and white-zinc paint removed from a glass plate were placed between electrodes ; on applying the current the direction of flow of water through the capillaries was observed. This direction indicated the sign of the charge held by the film. Whilst pure powder pigments became positively charged, these

pigments in linseed oil became negatively charged. Thus, whilst the electrokinetic effect of the pigment tends to bring moisture to the iron on which it is spread, the electro-osmotic effect of the paint film is to dewater the anodic areas of the iron. Further experiments illustrated the different behaviour of the two sides of the film, which was removed from the glass with a razor blade owing to the " air " side having a continuous film of linseed oil, and the " glass " side having an interrupted film due to the blade cutting through some of the pigment particles.—R. A. R.

ANALYSIS

Photocolorimetric Method for Determination of Niobium in Steel. A. L. Davydov, Z. M. Vaisberg, and L. E. Burkser. (Zavodskaya Laboratoriya, 1947, vol. 13, Sept., pp. 1038–1043). [In Russian].

Semi-Micro Determination of Chromium and Vanadium in Ferrous Metals. B. A. Generozov. (Zavodskaya Laboratoriya, 1947, vol. 13, Sept., pp. 1043–1048). [In Russian].

Rapid Colorimetric Method for the Determination of Phosphorus in Cast Iron. K. A. Matveeva. (Zavodskaya Laboratoriya, 1947, vol. 13, Sept., pp. 1136–1137). [In Russian].

Colorimetric Determination of Small Quantities of Aluminium in Steel. I. K. Kuskova. (Journal of Analytical Chemistry, U.S.S.R., 1947, No. 2, pp. 7–16 : [Abstract]. Analyst, 1948, vol. 73, Feb., pp. 114–115).

Experience with Photometric Procedures for the Determination of Metals. H. Cox. (Metallurgia, 1948, vol. 37, Mar., pp. 270–274). The application of photometric technique during the last four years for the determination of metals is surveyed and some of the difficulties are discussed. A method of determining chromium in steel without using silver nitrate as a catalyst, and a composite method for chromium, molybdenum, and iron in welding fluxes are described.—R. A. R.

Methods for the Rapid Determination of Gases in Metals. Considerations on the Rôle of Analytical Chemistry in Wartime. G. Chaudron. (Bulletin de l'Association Technique de Fonderie, 1940, Jan.–Feb., pp. 2–7). A brief survey is presented of methods for the rapid analysis of gases in metals.—J. C. R.

Oxygen Recorded for Industrial Gases. (Energie, 1948, vol. 32, Apr., p. 106). The American " Magno-Therm " oxygen recorder is described. This instrument, which utilizes the paramagnetic properties of oxygen, consists essentially of an electrically heated resistance wire in the field of a permanent magnet. Oxygen is attracted by the field, heated by the wire, and then, losing its paramagnetism on heating, is displaced by fresh cold oxygen. There is thus a flow of gas over the wire, which covers it and lowers its resistance. The drop in resistance is recorded.—M. A. V.

Hydrogen, Nitrogen and Oxygen in Ferrous Metals. E. C. Pigott. (Metallurgia, 1947, vol. 36, Oct., pp. 335–338 ; vol. 37, Nov., pp. 23–27 ; 1948, Jan., pp. 129–132 ; Feb., pp. 181–184 ; Mar., pp. 263–266). Accounts are given of the chemical and physical properties, and the occurrence and determination in iron and steel, of hydrogen, oxygen, and nitrogen.—C. O.

The Separation of Uranium and Iron. F. Vlasák and L. Kosinová. (Chemické Listy, 1948, No. 2, pp. 32–34). [In Czech]. Iron and uranium may be separated by shaking a mixture of their chlorides in 20% hydrochloric acid and ether; uranyl chloride remains in the aqueous layer, and the ferric chloride is transferred to the ether layer. The last trace of iron may be removed from the aqueous layer by the carbonate method.—R. A. R.

Semi-Electrometric Titration Method for Titanium in Ferrotitanium. R. Lannet. (Revue de Métallurgie, 1947, vol. 44, Sept.–Oct., pp. 286–291). The potentiometric method of Klinger, Stenger, and Koch for the determination of titanium in ferrotitanium is discussed and an improved semi-electrometric method described. A 1-g. sample of the ferrotitanium is dissolved in 100 c.c. of 1 : 3 HCl at 50–60° C. and filtered; to the filtrate and washings, of hot 10% HCl solution, is added 70 c.c. conc. HCl, 10 g. zinc for reduction and, at the end of the reaction, 2–3 g. of $MgCO_3$. The reduced solution is then transferred to a Strohlein electrometric titration apparatus and 20 c.c. of 10% ammonium sulphocyanide solution is added ; titration is then carried out with a solution of $CrCl_2$. This is made by dissolving 2 g. Cr_2Cl_3 in 100 c.c. of 1 : 2 HCl, and reducing this with 10–15 g. of zinc under a layer of amyl alcohol, and the solution is kept under amyl alcohol during titration. A calomel half-cell is used as a reference electrode and titration is carried out carefully. The galvanometer first remains stable and then deflects, gently at the beginning and then sharply ; at the point of maximum instability a further titration with ferric chloride is made until a permanent red coloration is obtained. The $FeCl_3$ solution is so made up that the volume (in c.c.) used is equivalent to the percentage of soluble titanium.

The residue from the original HCl attack is ignited, treated with HF plus two to three drops of H_2SO_4 and fused with potassium bisulphate ; the titanium is then determined by the H_2O_2 colorimetric method. The sum of these results gives the total titanium in the ferro-alloy. Comparison with other methods indicates considerable accuracy.

Rapid Determination of Cobalt in Steels. B. E. Jaboulay. (Revue de Métallurgie, 1947, vol. 44, Sept.–Oct., pp. 302–306). A new method for the rapid determination of cobalt in steels, using sodium cyanide, is described. After giving results of tests by this method, the chemical reactions are discussed. By boiling 0·1 g. of the steel sample in 15 c.c. dilute HCl a rough idea of the approximate amount of cobalt in the steel can be deduced from the colour of the liquid (which varies from very light green to blue). The operating methods are given for steels with the following amounts of cobalt : Up to 3·5%, 3·5% to 7·5%, and 7% to 15%. For steels containing up to 3·5%, a solution is prepared by taking 1 g. of steel, attacking it with 30 c.c. dilute HCl and adding an amount of iron equal to the other elements present in the steel. A sodium cyanide solution and soda are added so that a mixture of cobalti-cyanide of cobalt and alkaline cyanide is formed. After filtering, the solution is titrated against silver nitrate using potassium iodide and sodium sulphate as indicators. The method is the same, except for minor adjustments, for the greater amounts of cobalt.—R. F. F.

Photocolorimetric Methods for the Analysis of Iron Alloys. III. Determination of Cobalt in Steel. A. M. Dynov and O. A. Volodina. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 137–144 : Chemical Abstracts, 1948, vol. 42, Feb. 20, p. 1150).

Spectrography. J. Byrt. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy, Part 4, Physical Apparatus for Metallurgical Measurements, 1947, Sept.). A very full account is given of the principles of spectrography, the different kinds of apparatus used, and their advantages and limitations for various applications.—R. A. R.

Spectral Analysis of Steel. V. G. Koritskil. (Bulletin de l'Académie des Sciences de l'U.R.S.S., Série physique, 1947, vol. 11, pp. 260–275 : Chemical Abstracts, 1948, vol. 42, Mar. 20, p. 1845). The methods of steel

spectroscopy by analysing samples of known composition were studied by standard methods ; modifications were made wherever necessary. For semiquantitative determination with the steeloscope, iron-rod and copper-disc electrodes were used to determine chromium, tungsten, manganese, vanadium, molybdenum, and nickel. A satisfactory method of analysis could be worked out for all elements with the exception of nickel and manganese. The different homologous pairs are tabulated. In quantitative determinations with the spectrograph, the influence of a third element in the alloy and the linearity of the working curves were studied. The influence of electrode materials (iron, aluminium, copper, and graphite) on working curves in the analysis with a steelometer was also studied.

Spectral Determinations of Some Metalloids. N. S. Sventitski. (Bulletin de l'Académie des Sciences de l'U.R.S.S., Série physique, 1947, vol. 11, pp. 319–325 : Chemical Abstracts, 1948, vol. 42, Mar. 20, p. 1845). To determine phosphorus in steel it is recommended to use the lines 2149·1 Å and 2136·2 Å. A carbon electrode is used as the second electrode in preference to iron, copper, aluminium or zinc. The diameter of the steel electrode should be about 50 mm. to avoid changes of intensity during the burning. The Fe line 2132·1 Å was used as a comparison line in the working curve. To determine carbon in iron alloys with the lines 4267 and 2297 Å it was found necessary to modify the standard spark generator. Carbon can also be determined approximately with a steeloscope.

Stable Working Curves As an Approach to Standard Methods of Spectrographic Analysis. W. H. Magrun. (Eighth Pittsburgh Conference on Applied Spectroscopy, 1947 : Bulletin of the British Non-Ferrous Metals Research Association, 1948, Mar., p. 77). The author claims that working-curve shifts are avoided in analysis of steels by proper choice of source-unit parameters and line pairs, and by determination of gamma for every line measured.

Quantitative Spectrochemical Analysis of Steel. J. Gillis and J. Eeckhout. (Analytica Chimica Acta, 1947, vol. 1, Dec., pp. 377–389). The operating conditions are described for the spectrochemical analysis of iron and steel, using solutions. Solutions are always homogeneous and the most widely different material, of any shape, and also finished products, can always be investigated under the same conditions. The technique described is based on Scheibe and Rivas' method. The Pfeilsticker interrupted A.C. arc was used as a light source. The whole of the investigation was carried out with a Hilger medium spectrograph. The results are very satisfactory and prove that an apparatus of moderate dispersion serves very well for the spectrochemical analysis of steel. Analysis-lines and standardizing tables are given for the determination of the contents of nickel, manganese, chromium, cobalt, titanium, aluminium, molybdenum, vanadium, zirconium, arsenic, copper, niobium, and tantalum.—R. A. R.

Spark Technique in Spectrographic Analysis of Slags. R. H. Steinberg and H. J. Belic. (Analytical Chemistry, 1948, vol. 20, Jan., pp. 72–73). A method is described for the quantitative spectrographic analysis of open-hearth slag ; it enables the silicon and calcium to be determined so that the lime/silica ratio can be rapidly obtained for control purposes.—R. A. R.

The Determination of Nitrogen in Nitrided Iron by the Ionic Bombardment Method. L. Moreau and G. Chaudron. (Académie des Sciences, 25 Oct., 1943 : Métaux, Corrosion, Usure, 1943, vol. 18, Sept., pp. 153–155). Pure iron was nitrided by heating in ammonia at 650° C. When subjected to ionic bombardment at ordinary temperature all the dissolved hydrogen but only part of the nitrogen was evolved. The specimen was impregnated with hydrogen by electrolysis and the ionic bombardment repeated a number of times. After the fourth impregnation with hydrogen no measurable volume of nitrogen was evolved.—J. C. R.

The Application of the Spekker Photoelectric Absorptiometer to the Analysis of Chromium Plating Solutions. W. J. Bayley. (Journal of the Electrodepositors' Technical Society, 1947, vol. 22, pp. 121–128). Methods for the rapid determination of trivalent and hexavalent chromium and iron in chromium plating solutions have been developed by applying the Spekker photoelectric absorptiometer to the measurement of light absorbed by the solutions. Trivalent and hexavalent chromium concentrations are estimated directly, using orange and blue glass filters respectively, whilst for the determination of iron, potassium thiocyanate is added to form the blood red complex, which is then estimated using a green filter.

The Design and Use of a Photoelectric Absorptiometer for the Analysis of Solutions Employed for the Electro-Deposition of Hard Chromium. H. E. Styles. (Journal of the Electrodepositors' Technical Society, 1947, vol. 22, pp. 129–154). Changes in chemical composition resulting from the use of chromic acid solution for electrodeposition are described together with the causes of such changes, their effects and methods whereby the solution composition may be maintained within satisfactory working limits. The necessary chemical analyses are somewhat tedious and time consuming, and a description is given of a photo-electric absorptiometer designed to overcome these difficulties. Details are given of the estimation of sulphate, chromic acid, iron, and trivalent chromium.

Method of Quantitative Micro-Analysis by the Measurement of the Absorption of X-Rays. A. Guinier. (Académie des Sciences, 4 Jan. 1943 : Métaux, Corrosion, Usure, 1943, vol. 18, Feb., pp. 36–37).—J. C. R.

The G. Lasègue Recording Microphotometer. (Métaux, Corrosion, Usure, 1943, vol. 18, Feb., pp. 34–36). A description of the above instrument and its operation is given.—J. C. R.

Determination of the Gases in Meteoritic and Terrestrial Irons and Steels. L. K. Nash and G. P. Baxter. (Journal of the American Chemical Society, 1947, vol. 69, pp. 2534–2544 : Chemical Abstracts, 1948, vol. 42, Feb. 10, p. 841). In a study of the gases present in siderites, a general survey was made of the methods by which gases can be liberated from meteoritic and terrestrial irons and steels. None of the currently available procedures is entirely satisfactory. The methods examined included heating *in vacuo*, fusion *in vacuo*, vacuum fusion with metallic flux, solution in fused salts, solution in aqueous copper salt solutions, solution in aqueous $HgCl_2$ solutions, solution in non-aqueous solutions, reaction with chlorine and bromine, reaction with iodine, electrolytic solution, solution in acids, liberation of gases by positive-ray bombardment, and liberation by mechanical broaching. Solution in aqueous solutions of $HgCl_2$ under carefully controlled conditions was found to be best, particularly if the steels do not contain too large a quantity of combined carbon. It was shown that previously determined values for the gases in meteorites are erroneous, and that meteoritic iron contains between 2 and 50 cu. mm./g. of hydrogen, nitrogen, carbon monoxide and carbon dioxide, and no readily detectable amount of methane or cyanogen. The essential similarity of the gases in terrestrial and meteoritic steel was indicated.

Contribution to the Determination of Vanadium in Steels and Ferro-Vanadium. R. Lannet. (Revue

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The Interrelation of the Engineering and Metallurgical Industries. Sir Arthur P. M. Fleming. (Institute of British Foundrymen : Foundry Trade Journal, 1948, vol. 84, Feb. 19, pp. 169–175). Advances in the design of prime movers and electric generators set new problems in metallurgy and involved changes in the compositions and processing treatments of the metals used. Reliability of the materials is of great importance, and to ensure this numerous inspection and testing methods are employed ; some of these methods, such as micro- and X-ray examinations and supersonic, fluorescent, and magnetic testing, are outlined. The metallurgical requirements of the gas turbine and the jet engine are discussed, and reference is made to (1) the production of non-corrodible steels, (2) the applications of electric furnaces, (3) electric welding, (4) powder metallurgy, and (5) the utilization of radio-active isotopes as tracer elements in the investigation of phase equilibria in metals and conditions near crystal boundaries. The article concludes with acknowledgment of the value of the work being carried out by the various research associations, industrial organizations, and academic bodies, and also of the co-operative effort for the interchange of knowledge between producer and user.—J. R.

Standardization in the Steel Industry. K. Mandybur. (Hutnik, 1946, vol. 13, Dec., pp. 631–646). [In Polish]. Designations for plain carbon and alloy steels are given, together with chemical and mechanical properties for a number of constructional steels. Designations for some high alloy steels are also suggested.—W. J. W.

Wire in the Automobile. F. T. Updike. (Wire and Wire Products, 1948, vol. 23, Jan., pp. 29–34). The innumerable uses of wire and rod in automobile construction are outlined.—R. A. R.

Modern Material Handling in a High Carbon Wire Mill. Le R. D. Seymour. (Wire and Wire Products, 1948, vol. 23, Jan., pp. 45–46). Electric hoisting equipment, gravity roller conveyers, and fork tractors for moving coils of wire in wire mills are described.—R. A. R.

Reflections on the Construction of Observation and Measuring Instruments. P. Chevenard. (Société d'Encouragement pour l'Industrie Nationale, 25 Mar., 1943 : Métaux, Corrosion, Usure, 1943, vol. 18, Mar., pp. 57–58). A brief account is given of the various factors that have to be taken into consideration when constructing measuring and recording instruments.—J. C. R.

The Operation of a Gas Fired Furnace for Vitreous Enamelling. S. E. A. Ryder. (Sheet Metal Industries, 1948, vol. 25, Feb., pp. 339–344).

Cleaning of Service Water in Steel Plants. S. P. Kinney. (Iron and Steel Engineer, 1948, vol. 25, Feb., pp. 56–59). The cleaning and straining of service water for steel-plant use are discussed and a description is given of a 30-in. self-cleaning unit capable of straining 30,000 gal. of water per hour, with a pressure drop of not more than 1½ lb.—J. R.

Removal of Dissolved Silica from Boiler Feedwater. M. E. Gilwood. (Energie, 1948, vol. 32, Mar., p. 79). This is an abridged translation of an article which appeared in Power, 1947, vol. 91, Aug., pp. 86–89. The processes described are, treatment with ferric sulphate, magnesia, sodium fluoride, and direct absorption using ionic exchange resins.—R. F. F.

Use of Water Treated with Hydrogen-Zeolite for Dissolving Boiler and Superheater Deposits. (Energie, 1948, vol. 32, Apr., p. 90). Water treated with hydrogen-zeolite softeners becomes acid and will remove deposits in boilers with no harmful effect on the metal. For cleaning boilers and superheaters, water treated with hydrogen zeolite is passed, at the rate of 85 l./min., for 6 or 8 hr. (or until the *p*H value at the outlet is 4·4). Laboratory tests show that the corrosion rate for metals is only 50% of that when 5% acid solutions are used. —R. F. F.

Treatment of Feedwater in Germany. W. W. Cerna. (Power, 1947, vol. 91, Sept. pp. 72–76, 158 : [Abstract]. Energie, 1948, vol. 32, Jan., p. 3a). An inspection of German power stations by an American commission is reported. Water treatments include : hot or cold lime-soda process for eliminating bicarbonates and sulphates ; ion-exchangers using synthetic resins of the Wofatit type ; elimination of silica ; filters made of quartz, calcium carbonate or partially roasted dolomite material ; mechanical and chemical deaeration ; use of ammonia and ammonium salts for conditioning feedwater ; filling boilers not in use for some period of time with nitrogen at low pressure ; and cooling towers.

A New Method for the Purification of Water for Industrial Use. E. N. Teterkin. (Stal, 1948, No. 2, pp. 177–182). [In Russian]. A description is given of a method of purifying water in which the special properties of newly settled sediments are utilized. The water is led into "suspension separators," where it percolates upwards through a bed of sediment, part of the sediment thereby going into suspension. This suspension is active in promoting the agglomeration and retention of the suspended matter contained in the water ; it also accelerates the precipitation of the solid phase during coagulation and softening. The use of suspension separators can reduce the size of the purification plant to one half or one third of the conventional size while making the purification five to six times more effective. Various designs of suspension separators are presented and discussed, and the method of calculating their dimensions for different operating conditions is given. The possibility of increasing their efficiency by imparting eddy-motion to the water is considered.—S. K.

Industrial Vacuum Melting. K. Fox, R. A. Stauffer, and W. O. Dipietro. (Iron Age, 1948, vol. 161, Feb. 19, pp. 64–70). The development of equipment for melting metals *in vacuo* is described with special reference to the pumps, valves, and instruments for producing, controlling, and measuring the vacuum.

Advantages of Integrating Manufacturing. G. E. Stedman. (Steel, 1948, vol. 122, Feb. 16, pp. 85–87, 119–122). A description is given of the manner in which the steel foundry, machine shop, and fabricating departments of the Omaha Steel Works in Nebraska are co-ordinated to cause steady production of snow ploughs, bulldozers, and heavy machinery.—R. A. R.

Use of Dry Ice for Shrinking Cast Iron Liner into Large Air-Compressor Cylinder. N. D. Mackay. (Journal of the South African Institution of Engineers, 1947, vol. 46, Dec., pp. 117–123). A description is given of the manner in which dry ice was used to shrink a cast-iron liner 33 in. in dia., 10 ft. long, to the high-pressure cylinder of a water-cooled air compressor.—R. A. R.

Patterning Stainless Steel. (Electroplating, 1948, vol. 1, Mar., pp. 203–204). Methods of producing permanent designs in shades of yellow, brown, and black on stainless steel are briefly described.—R. A. R.

Joining Metals with Adhesives. G. Génin. (Machines et Métaux, 1948, vol. 32, Feb., pp. 53–58). The use of various adhesives, mainly of the rubber and synthetic-resin type, for joining metals, is reviewed.—R. F. F.

Adhesives for Gluing Thin Metal Sheets. F. A. Westbrook. (Steel Processing, 1948, vol. 34, Jan., pp. 26–28). A procedure for making lap joints in sheet metal with a synthetic-resin adhesive is described. This consists of two components, a powder and a liquid. After

thorough cleaning of both surfaces the liquid is applied to them and, while still wet, the powder is sprinkled on. After allowing them to dry they are pressed together by steam-heated platens at a pressure of 300–500 lb./sq. in. The process can be applied to carbon steel and stainless steel sheets. Data on the shear strength of joints are presented.—R. A. R.

Tonnage Oxygen Plant. T. Bishop. (Iron and Coal Trades Review, 1948, vol. 156, Apr. 9, pp. 733–739). After briefly reviewing experiments with the use of oxygen in French iron and steel works, the author describes the "Oxyton" plant for producing oxygen of medium purity on a large scale, of which the special features are the use of turbo-compressors, regenerators, expansion turbines, and a patented multiple-pressure rectification system. Designs are complete for plants to produce 30, 200, and 800 tons/day of oxygen, and a fairly detailed description of an existing plant producing about 90 tons of oxygen of 92% purity per day, using three units in parallel, is given. The power consumption is at the rate of 0·53 kWh./cu. m. of 100% oxygen.—R.A.R.

Theoretical Aspects of Air Separation. M. Ruhemann. (Institution of Chemical Engineers and the Physical Society, Joint Conference on Developments in the Industrial Production and Use of Gaseous Oxygen, Feb., 1948, Advance Copy, pp. 15–21).

Modern Gaseous Oxygen Production Methods. P. M. Schuftan. (Institution of Chemical Engineers and the Physical Society, Joint Conference on Developments in the Industrial Production and Use of Gaseous Oxygen, Feb., 1948, Advance Copy, pp. 22–28).

Some Notes on the Economics of Medium Purity Oxygen. J. R. Park. (Institution of Chemical Engineers and the Physical Society, Joint Conference on Developments in the Industrial Production and Use of Gaseous Oxygen, Feb., 1948, Advance Copy, pp. 29–31).

The Production of High-Percentage Gaseous Oxygen and Applications in Organic Heavy Industry. A. Rasmuson. (Teknisk Tidskrift, 1948, vol. 78, Mar. 13, pp. 155–159). [In Swedish]. After describing the Linde-Frankl method and the American method of producing oxygen of 98% and 99·5% purity respectively, and giving details of the Collins heat exchanger and Kapitza expansion turbine used in the American process, the author discusses large-scale applications of oxygen. These applications include German methods of producing synthesis gas from brown coal, brown-coal coke, and coke breeze, as well as the American Hydrocol process employing natural gas as a raw material.—R. A. R.

Reflections on the Present Position of Silicosis Prevention and Silicosis Research in German Mining. M. Landwehr. (Glückauf, 1948, vol. 81–84, Mar. 13, pp. 171–186).

BOOK NOTICES

GORTER, C. J. "*Paramagnetic Relaxation*," 8vo, pp. vii + 127. London, 1947: Elsevier Publishing Co. (Price 12*s*.).

The phenomenon of relaxation in paramagnetic salts is, roughly speaking, analogous to that of dielectric loss in an alternating electric field, the variation of the intensity of magnetization being unable to follow an alternating magnetic field of sufficiently high frequency. If one plots graphically the variation of the in-phase susceptibility χ' as a function of frequency V, one obtains a relation typified by $\chi' = \chi_0/(1 + \rho^2V^2)$. Alternatively, one may study the absorption of energy from the alternating field, which is measured by the out-of-phase susceptibility χ''. The latter quantity is given by a formula of the type $\chi'' = \chi_0\rho V(1 + \rho^2V^2)$. The quantity χ_0 is the susceptibility at zero frequency, while ρ is a quantity of the dimensions of a time characteristic of the particular substance. It may happen that more than one such constant is involved, in which case the expressions for χ' and χ'' become more complicated, but, provided that the frequency range used is big enough, all the time-constants ρ can be determined by a fairly straightforward analysis of the experimental curves for χ' or χ'' (either of which is theoretically sufficient to determine the ρ's). In dielectrics it is not usually possible to give any particularly illuminating physical interpretation of the time constant associated with the "viscous" drag which prevents the dipole from orientating itself freely, but, in the paramagnetic salts, some progress has been made. The salts studied by Gorter and his collaborators were the so-called "normal" paramagnetics, that is those that obey Curie's law that χ is proportional to 1/T. Since the departure from Curie's law is usually a measure of the interaction between the atomic magnets, the normal paramagnetics are these salts in which the paramagnetic ions are kept apart by large quantities of diamagnetic material, *e.g.*, water molecules. Such salts are, *e.g.*, $Gd_2(SO_4)_3.8H_2O$, $FeNH_4(SO_4)_2.12H_2O$. These salts, the ions of which only interact weakly with one another, are those which are the most useful in the production of very low temperatures by the magnetic cooling method, and the phenomenon of relaxation was discovered by Gorter while attempting to get information about the process of magnetic cooling. The Curie points of some salts are only a few hundredths of a degree absolute, so that there is no likelihood of ferromagnetic effects setting in even at liquid-helium temperatures.

Such a salt thus consists of weakly interacting magnetic ions each subject to an electric field due mainly to the water molecules in the crystal lattice. It is believed that two main effects are responsible for paramagnetic relaxation, first the coupling between magnetic ion and lattice, which occurs mainly by virtue of this crystalline electric field, and which is usually known as the ion-lattice coupling, secondly the coupling of the ions with one another, usually known as ion-ion coupling. The ion-lattice coupling enables the energy of interaction of an ion with a magnetic field to be converted into thermal energy of vibration of the crystal lattice, while the ion-ion coupling enables the ions to share energy with one another.

The book brings together practically all the published material on the subject from the original discovery by Gorter in 1935 up to the outbreak of war, together with a further work on the subject carried out in Holland during the war. (Some account of the very difficult conditions of work in 1944–45 is given in the preface). Accordingly, there is only a brief mention of the recent remarkable work on nuclear paramagnetism, and of the work by Zavoisky and others on the determination of the energy-levels of a paramagnetic ion by resonance methods. The allied subject of irreversible heating effects in an alternating

magnetic field when the temperature is only a fraction of a degree (and ferromagnetic or similar effects are beginning to appear) is briefly mentioned.

Chapter I describes the concept of "normal" paramagnetism, derives some results in thermodynamics and in the general theory of absorption and dispersion in alternating fields that are needed later in the book, and gives a very clear account of the present theoretical and experimental knowledge of the *static* susceptibilities of the "normal" paramagnetic salts. If the paramagnetic ion is a rare-earth, the crystalline electric field has very little effect on the susceptibility, because the incomplete shell of electrons responsible for paramagnetism is "buried" inside the atom, but if the ion is in the iron group, the incomplete shell is the outer one and the effect of the crystalline field is to "quench" the orbital magnetic moment, leaving effective only the moment due to the electric spins.

Chapter II is a description of experimental methods. Chapter III contains an analysis of the results obtained by the three main methods of measuring the dispersion, measuring the absorption, and measuring the two simultaneously by a bridge method. Chapter IV gives an account of theoretical developments, the cornerstone of which is the thermodynamical theory of Casimir and du Pré, in terms of which the results have been analysed. The basis of this theory is that one may consider the magnetic ions as forming by themselves a statistical assembly which can be regarded as having a definite temperature, not necessarily that of the crystal lattice. The interaction between the ions determines the rate at which differences in the ion-temperature at different places disappear, the associated time-constant being the ion-ion relaxation time. Since this time is always small compared with the time-constant associated with interaction between ion and crystal lattice, the concept of the "temperature of the ions" is a valid one. The ion-lattice relaxation time specifies the rate of transfer of energy between the assembly of ions and the crystal lattice.

Attempts to calculate the two relaxation times theoretically have been much less successful, the theories of ion-ion relaxation time being rather rough, and those of ion-lattice relaxation time being both difficult to carry through consistently, and in disagreement with experiment in some respects. The author gives a very fair account of the present position. Chapter V continues the discussion of the results in the light of these theories, but the difficulties and discrepancies are carefully pointed out. The different methods do not always give consistent results for the ion-lattice relaxation time, but the discrepancies are never serious. The ion-ion relaxation time is only obtainable from the absorption measurements.

The book is very well printed on quite nice paper. There are very few misprints but an occasional slip in grammar is found. This book will certainly be of permanent value to anyone working in the field of magnetic cooling, though conditions in a paramagnetic salt are so different from those in iron that it is hard to see yet any points of contact with practical problems connected with magnetic materials. The author himself modestly states that the subject "is not an important chapter in modern physics." If one may be allowed a criticism it is that the theoretical parts are unduly compressed. For example, the account of the Jahn-Teller effect on p. 12 would be unintelligible to anyone who does not know the subject.—H. N. V. Temperley.

Schwarzkopf, P. "*Powder Metallurgy. Its Physics and Production.*" 8vo, pp. xii + 379. Illustrated. New York, 1947 : The Macmillan Co. (Price 40*s.*)

The book has been written with the collaboration of C. G. Goetzel, G. Stern, R. Steinitz, and W. Leszynski; it contains a great deal of information about the industrial processing of metal powders and the products obtainable. It also reviews the theories on which powder metallurgy is based.—R. E.

NEW PUBLICATIONS

American Institute of Mining and Metallurgical Engineers. "*Seventy Five Years of Progress in the Mineral Industry* 1871–1946." Pp. 810. New York, 1948 : The Institute. (Price $6.00).

American Society for Testing Materials. "1947 *Supplement to Book of A.S.T.M. Standards Including Tentatives.*" 8vo, Part IA, "*Ferrous Metals.*" Pp. xiii + 403. (Price $4.00). Part IIIA, "*Nonmetallic Materials—Fuels, Petroleum, Aromatic Hydrocarbons, Soaps, Water, Textiles.*" Pp. xiii + 437. (Price $4.00) Part IIIB, "*Nonmetallic Materials—Electrical Insulation, Plastics, Rubber, Paper, Shipping Containers, Adhesives.*" Pp. xiii + 305. (Price $4.00). Philadelphia : The Society.

Bargone, A. "*Chimica fisica del processi di fabricazione della ghisa e dell'acciaio.*" Pp. 245. Udine, 1946. Del Bianco.

Brailsford, F. "*Magnetic Materials.*" Pp. 156. London, 1948 : Methuen and Co., Ltd. (Price 6*s.*).

Buttgenbach, H. "*Les Minéraux de Belgique et du Congo Belge.*" Pp. 573. Illustrated. Paris, 1947 : Dunod. (800 Belgian francs).

Chaussin C. and G. Hilly. "*Métallurgie.*" Tome I, "*Alliages Métalliques.*" 8vo, pp. xiv + 178. Illustrated. Paris, 1948 : Dunod. (Price 380 frs.).

Couard, A. *L'Utilisation Pratique des Palplanches Métalliques. Leurs Applications—Leur Calcul et Leur Choix.* Deuxieme édition revue et augmentée. 8vo, pp. 161. Illustrated. Paris et Liége, 1945 : Libraire Polytechnique, Ch. Béranger.

Low, D. A. "*A Pocket Book for Mechanical Engineers.*" Edited by B. B. Low. New Edition. 16mo, pp. 778. Illustrated. London, 1948 : Longmans Green and Co. (Price 15*s.*).

Ludwig, K. and W. Lohmann. "*Schweissen der Eisenwerkstoffe.*" (Stahleissen-Bücher Bd. 6). 2 Aufl. 8vo, pp. 456. Düsseldorf, 1948 : Verlag Stahleisen. (Price 37.00 RM.).

Mahin, E. G. "*Elementary Physical Metallurgy. With Emphasis on Ferrous Metallurgy.*" Brooklyn, N.Y.: Chemical Publishing Co. (Price $6.00).

Mason, C. "*Introductory Physical Metallurgy.*" 8vo, pp. 130. Cleveland, Ohio : American Society for Metals. (Price $3.00).

Rohrmann, A. "*Das Schmieden von Gesenken im Gesenk.*" 8vo, pp. 58. Illustrated. München, 1947 : Hanser. (Price 2.80 RM.)

Rubio Felipe, L. A. "*Problemas de tecnologia quimica.*" Vol. I, "*Metalurgia, sus operaciones y electrometalurgia.*" Pp. 238. Madrid, 1947 : Editorial Viellegas. (Price 50 pesetas).